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visualization of mind: visual exploration of brain activity

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visualization of mind

visual exploration of brain activity

by Bilegsaikhan Baasanjav

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dedication

This thesis is dedicated to the memory of my grandfather, Mangaljav Damba.
For his love and encouragement that always supported me.

acknowledgement

Much gratitude to the following people and organizations for their support and guidance:

Daniel DeLuna
Chris Jackson
Shaun Foster
Peter Byrne

Rochester Institute of Technology

contents

abstract

Since ancient times, philosophical and religious thinkers have made attempts to understand the nature of the mind. Today, new developments in technology enable scientists and researchers to explore the brain's complex physical activity, revealing a deeper mental reality. Moreover, the emergence of low-cost biometric devices gives nonscientific communities an ability to explore usage of biometric data in variety of ways.

This project explores visualization of human brain activity using electroencephalogram neural interface to create a visually engaging and meaningful user experience. The implementation of the project takes a form of an interactive installation. It projects the visual form, whose visual parameters are changed in real-time based on the participant's brain wave signal values. The brain activity is monitored by the electroencephalogram (EEG) neural interface, which transmits the brain wave signal data of the participant's brain activity to the computer program. The program analyzes signal values and manipulates the visual form.

In order to create a meaningful and useful experiences, the research was conducted in areas of cognitive science, philosophy, symbolism and visual design. The visual form was designed based on the Kalachakra Mandala, a circular diagram used in the Tibetan Buddhist tradition. It was selected as a reference because of its deep philosophical meaning and purpose.

The user experience was evaluated based on qualitative methods that consisted of interviews and written questionnaires. It provided insights into the user's experience and helped to determine potential applications. The method of recording and analyzing mathematical data of the brain activity was used to determine a credible quantitative evaluation method to be used in the future.

The evaluation showed the majority of participants who tested the installation had a calming and relaxing experience. Many of them indicated the project has a high potential to be used for meditation and therapy purposes.

keywords

visualization of mind, interactive installation, eeg visual, meditation, mindfulness, cognitive science, processing, brain computer interface, mandala

introduction

introduction

The idea of this project originated from a personal interest in philosophy. Many great thinkers and philosophers throughout history have tried to explain how the mind works. Despite their immeasurable efforts and contributions, the workings of the mind still remains one of the many enigmatic subjects of nature.

This project approaches the subject of the mind from a visual perspective. It explores means to visualize brain activity in visually engaging and meaningful ways using biometric technology. The following questions helped me to define the goal and scope of the project:

- Can brain activity be visually represented?
- What kind of visual form would it take?
- Can environment interact with the brain?
- What are potential applications for visualizing brain activity?

The primary goal of the project is to explore visualization of brain activity to create meaningful and visually engaging user experience.

situation analysis

Monitoring of the participant's brain activity is necessary for the implementation of this project. There are number of brain imaging methods that enable physicians and scientists to monitor brain activity. Commonly used methods are Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Positron Emission Tomography (PET) and Electroencephalography (EEG). Among these, EEG is one of the earliest and most inexpensive methods. It monitors electrical activity of the brain by attaching electrodes along the scalp. It continues to be a popular method for researchers because of its ability to track activities on a millisecond-level, which is not possible with other methods. This feature, paired with the availability of several low cost consumer and research grade EEG devices makes EEG the most appropriate brain activity monitoring method for the implementation of the project.

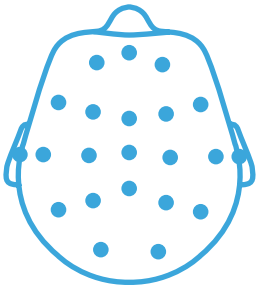

Figure 1. Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain

EEG works by recording brain wave signals. Signals have different frequency bands; they are named alpha (8–13 Hz) delta (1–4 Hz), theta (4–8 Hz), beta (13–30 Hz) and gamma (30–70 Hz). Each frequency band is commonly associated with different mental states (Fig. 2). For example, the increase in the alpha wave signal value can be detected when one is in the state of relaxed wakefulness, whereas the increase in gamma wave signal value corresponds to the state of concentration and focus.

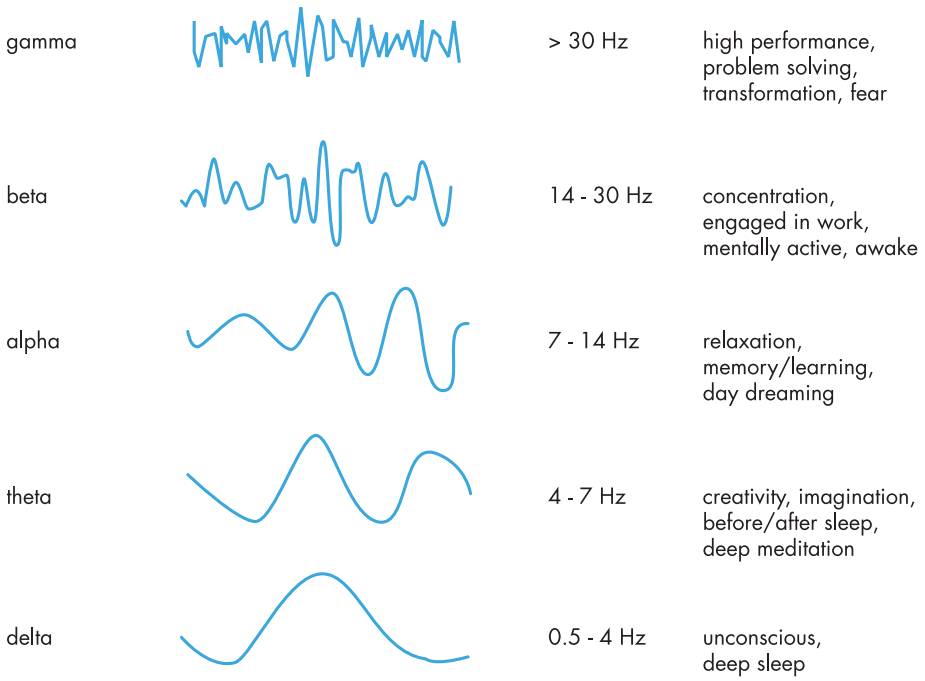

Figure 2. Brain wave signals correspond to different mental states

existing applications

Traditionally, EEG has been used as a medical tool to diagnose brain disorders and the research grade EEG equipment costs several thousand dollars. Today, a continuous decrease in the cost of digital devices makes EEG devices more affordable and accessible. Over recent years, several consumer and research level EEG brain computer interface (BCI) devices have been released. These devices allow the research community to build and experiment with projects for a wide range of non-medical purposes, which was not achievable before.

assistive technology

One of the first non-medical applications of an EEG was creating assistive devices for people with paralysis like Amyotrophic Lateral Sclerosis (ALS) disease. In 2009, Toyota and the research foundation RIKEN built a wheelchair for people with paralysis or severe disabilities[1]. The wheelchair has a skull cap EEG sensor and a display that assists with control. It could successfully respond to the driver's brain wave signals to complete commands like turning left, turning right and stopping. It proved to be successful and had potential to be further used as an interface for prosthetic and human enhancement devices.

1 "Toyota Makes a Wheelchair Steered by Brain Waves." Accessed February 22, 2016. http://www.gizmag.com/toyota-wheelchair-powered-brain-waves/12121/.

communication

In 2014, the international team of researchers and engineers published a paper describing the first successful attempt of brain-to-brain communication[2]. They successfully transmitted the words "hola" and "ciao" across the Internet between two human subjects using EEG and robot-assisted and image-guided transcranial magnetic stimulation (TNS). Although it is far from being practical, it might be the first step of future communication technology.

game and entertainment

One of the most successful and promising EEG applications is considered the gaming industry. Neurosky was one of the pioneer companies that introduced EEG game controllers into the market with headset MindWave[3], the device designed for gaming and simple video applications. Researchers think EEG games might be a possible solution to help those with attention problems, especially children.

neuromarketing and advertisement

Neuromarketing is a relatively new field of marketing research. Instead of conventional methods of consumer testing, it studies consumers' cognitive response to marketing stimuli. Researchers and companies that use neuromarketing believe traditional methods produce inaccurate results because participants can never express their unconscious feelings. Therefore using EEG help the researchers find out how people really feel at their subconscious level when they make decisions about the product or service.

mental health

Mental health is an important component of the overall health system. It includes our emotional, psychological, and social well-being. With modern-day advancements in information and communication technology, the human brain is exposed to an enormous amount of information, thus creating information fatigue–a stress disorder which affects mental and physical health[4]. There are consumer level EEG devices available in the market that monitor a user's brain activity and help people to relax and practice meditation.

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2 Carles Grau et al. "Conscious Brain-to-Brain Communication in Humans Using Non-Invasive Technologies." PLoS ONE 9, no. 8 (August 19, 2014): e105225. doi:10.1371/journal.pone.0105225.

3 "EEG Headsets | NeuroSky Store." Accessed April 11, 2016. http://store.neurosky.com/.

4 White, Marsha, and Steve M. Dorman. "Confronting Information Overload." *The Journal of school health* 70.4 (2000): 160-1. ProQuest. Web. 11 April 2016.

thesis statement

This project explores methods of visualizing brain activity using an electroencephalogram neural interface to create a visually engaging and meaningful user experience.

research

research summary

I began my investigation with research on cognitive psychology and its history. My intention was to understand how the mind works from a cognitive science perspective. It was surprising to learn it was not until the nineteenth-century that we started to unravel the structure of mind, revealing the fact there are conscious and unconscious minds. The conscious mind is a set of cognitive functions such as perception, memory, thinking and emotion, that we are aware of. Among the most influential thinkers investigating consciousness was the eighteenth-century philosopher Immanuel Kant. He is known for his theory, which speculated that we constantly build a picture of our surroundings rather than merely document events, and human perceptions are not based on what exists, but rather somehow created—and constrained—by the mind. During his time, psychology was not an independent subject but merely a general category. It was later, in the nineteenth-century, when physiologist E. H. Weber conducted a simple experiment that led to a new stage of psychology, one which is based on experimentation. Subsequently, many scientists like Wilhelm Wundt, William Carpenter, Charles Peirce, William James and Carl Jung delved into the subject and uncovered facts about the unconscious mind. The result of their studies revealed the unconscious mind has knowledge unknown to the conscious mind, and massive amounts of information we perceive are processed outside of our awareness, dictating our behavior.

Further research brought me to works of influential psychiatrist Carl Jung on symbolism and psychology. One book particularly drew my attention. *The Red Book: Liber Novus*[1] is a collection of diaries he made during his self-experimentation with unconsciousness . During the experimentation, he documented his experience through written notes and hand-drawn illustrations. The illustrations are very sophisticated and have a clear resemblance with the mandala symbol. It was moments of struggle during experimentation when Jung started drawing mandalas, which helped him to bring order and balance to his psychic state. He wrote:

1 C. G. Jung, Sonu Shamdasani, and C. G. Jung. *The Red Book: Liber Novus. 1st ed. The Red Book: Liber Novus vols. Philemon Series.* New York: W.W. Norton & Co, 2009.

> I had to let myself be carried along by the current, without a notion of where it would lead me. When I began drawing the mandalas, however, I saw that everything, all the paths I had been following, all the steps I had taken, were leading back to a single point— namely, to the mid-point. It became increasingly plain to me that the mandala is the center. It is the exponent of all paths. It is the path to the center, to individuation.[2]

In addition, he observed that many of his patients' drawings were similar to mandala form as well. He concluded that mandala is the symbol or archetype of psychic unity, and appears as a natural attempt of self-healing, especially when one is in psychic disorientation.

The Mandala is a circular pattern very important and significant in Buddhist tradition. It is not a mere aesthetic illustration; it is a precisely constructed structure made by symbols with deep religious and philosophical meanings. Structurally, it consists of symbols placed in opposite sites, but grouped together by the center core bringing balance. According to the Tibetan Buddhist philosophy, mandala serves as a support for meditation, for visualization and for the attainment of the enlightenment. It represents both the outer (the universe) and inner cosmos (mind), and their relationship. *The Mandala: Sacred Circle in Tibetan Buddhism*[3] has a clear representation of structural correspondences between Tibetan mandala and the human body.

In both Jung's view and Tibetan Buddhist philosophy, the goal is to go through transformation to experience what they describe as Self, Buddhahood or Wholeness, and the visual representation of the Self or Buddha nature is the center nucleus or heart of the mandala.

The deeper I researched, the more I was convinced that mandala is not only the aesthetically interesting form to portray mind, but it also has philosophical and religious meanings that aid to meditation and visualization.

During the design process, I selected the Kalachakra Mandala as a basis of the visual form. The Kalachakra Mandala is a sand mandala constructed during the Kalachakra initiation ritual, and it is considered to be the most complex mandala in Buddhist tradition. The two books *The Mandala: Sacred Circle in Tibetan Buddhism* and *The Wheel of Time Sand Mandala: Visual Scripture of Tibetan Buddhism* were the most referenced resources. They cover meaning, structure and information on construction of the Kalachakra Mandala in great detail that helped the design process.

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2 Radmila Moacanin, Essence of Jung's Psychology and Tibetan Buddhism : Western and Eastern Paths to the Heart (2nd Edition). Somerville, MA, USA: Wisdom Publications, 2003. Accessed February 25, 2016. 28.

3 C. G. Jung. *Mandala Symbolism*. [1st Princeton/Bollingen paperback ed. Princeton/Bollingen Paperbacks, 266. Princeton, N.J.]: Princeton University Press, 1972.

For the implementation of the installation, an open source programming language Processing is used. The books and online resources about Processing were regularly referenced during the development of the final prototype.

review of literature

psychology

Subliminal: How Your Unconscious Mind Rules Your Behavior
Leonard Mlodinow
Vintage Books
2013

This book explains how surprising our subliminal mind works and how actively it influences our conscious experience of the world. It begins explaining how our unconscious mind works by referring to important scholars' work and experiments in the history of cognitive psychology. It describes how our minds misperceive our relationships with family, friends; and how we misremember important events in our lives, changing our memories along the way. The book was a good introduction to the subject, well written, entertaining and easy to understand.

Man and His Symbols
Carl Gustav Jung, Marie-Luise von Franz
Dell Pub.
1968

Influential Swiss psychiatrist Carl Gustav Jung's last work where he explains the importance of symbolism, particularly as revealed in dreams. He emphasizes the significance of knowledge of unconscious – knowledge communicated through dreams and symbols. Illustrations and figures were valuable reference to develop a visual concept.

The Red Book: Liber Novus
Carl Gustav Jung, Sonu Shamdasani
W.W. Norton & Co
2009

This manuscript was crafted by Carl Gustav Jung between 1915 and circa 1930. He was self-experimenting by voluntarily confronting the unconsciousness through willful engagement. He documented his experience in small journals from where he transcribed notes into manuscript. The book contains

illustrations created to represent his visual experience. The illustrations were main object of study and important reference that helped to form a visual concept for the installation.

Mandala symbolism
Carl Gustav Jung
Princeton University Press
1972

Carl Jung makes a deep analysis on illustrations drawn by his patients, comparing them to the mandala, symbol that appears in philosophical and religious texts throughout history, especially in Tibetan Buddhism. Most of the drawings had a close resemblance to the mandala, even though patients didn't have any prior knowledge about it. He hypothesized it was a visual message transmitted by an unconscious mind to represent its state or convey a message. The analysis of mandala illustrations accompanied with their interpretations was helpful to understand the psychological meaning behind the illustrations.

The Mandala: sacred circle in Tibetan Buddhism
Martin Brauen
Shambala Publications
1998

This book is a translation of the Martin Brauen's original book in German published in 1992. Martin Brauen shares with the reader his detailed study of the meaning, function and rituals related to the Kalachakra Mandala. It contains beautiful illustrations, photos, and diagrams that are extremely helpful for readers to understand meaning and structure of mandala forms. The last chapter of the book discusses notions of western philosophy and science of mandala symbols. It specifically mentions Carl Jung's view on collective unconsciousness, archetype and symbolism, and how it relates to the mandala.

The Wheel of Time Sand Mandala: Visual Scripture of Tibetan Buddhism
Barry Briant
Snow Lion Publications
2003

The book has richly illustrated pages explaining stages of constructing the Kalachakra sand mandala during the Kalachakra ritual. It covers philosophical and religious meaning behind symbols used in the mandala. Each stage of the construction is explained in great detail, which helped me to design the visual form for the installation.

design

Generative art: a practical guide using processing
Matt Pearson
Manning
2011

The book starts with the brief discussion of the history of algorithmic and generative art. Then it presents a variety of code examples that are clearly divided into steps with explanations. The book was the primary reference for designing the visual form, which was used to test for the potential application of live performances.

Interaction of Color
Josef Albers
Yale University Press
2013

The author explains the principles of color theory in simple and efficient manner. He explains the perception of color and how creating an interaction between multiple colors can change that perception. *The Interaction of Color* consists of exercises that help readers reinforce what they learned from each section.

technical

Learning Processing: a beginner's guide to programming images, animation, and interaction
Daniel Shiffman
Morgan Kaufmann/Elsevier
2008

In addition to being a solid introductory book of programming in Processing language, it shows references of information, techniques, and extra libraries and other topics to continue develop projects beyond the scope of the text.

Language Reference (API) for Processing
Processing team
2001
https://processing.org/reference/
Accessed March 12, 2016

This is the official Processing programming language reference site. It contains well-organized explanations of every function, variable and features you can use when you write a Processing program. It was a frequently referenced resource when I was writing a code for the program for the installation.

Muse Developers
Interaxon Inc.
2015
http://developer.choosemuse.com/
Accessed March 12, 2016

This is the official reference site for the Muse EEG headband developers. It provides technical information about Muse headband. It contains information on the available data, the API references for the software developer kit, and tutorials that help researchers and developers to easily get started. The developers have free access to a variety of tools needed to develop their custom applications.

oscP5
Andreas Schlegel
2011
http://www.sojamo.de/libraries/oscP5/
Accessed Feb 12, 2016

oscP5 is an implementation of the Open Sound Control protocol for the Processing environment. The library is used to receive the brain wave signals from EEG neural interface in the Processing environment. The resource contains instructions, examples and class reference documents.

others

Interactive experience in the digital age: evaluating new art practice
Linda Candy, Sam Ferguson
Springer
2014

This book explores development of the interactive digital art. It discusses the difference and the problems of using formal Human Computer Interaction (HCI) evaluation methods, and suggests new methods of evaluating digital art based on practitioners feedback. The book was a good reference to form an evaluation strategy for the project.

Sense and sensibility: evaluation and interactive art
Kristina Höök, Phoebe Sengers, Gerd Andersson
ACM Press
2003

This paper describes a two-tiered evaluation method authors developed in order to evaluate an interactive art piece. The paper concludes traditional HCI evaluation methods are not suitable for evaluating interactive art projects. It also provides valuable case studies.

process

concept

The concept of the project was to create an immersive experience of observing and interacting with the visual representation of the mind or brain activity. It takes the form of an interactive installation, where the participant can see and interact with the visual form that was manipulated by the participant's brain activity.

installation

The main components of the installation are the wearable EEG neural interface, audio speakers, computer, projector, and wireless light (Fig. 3). The interactive session starts when the user wears an EEG neural interface, which sends brain wave signal stream data to the computer via Bluetooth connection. The computer receives the input signal stream, and forwards them as an input parameter to the Processing sketch, which is programmed to manipulate the light and the visual form projected on the screen. The audio is played in the background to enhance the overall user experience.

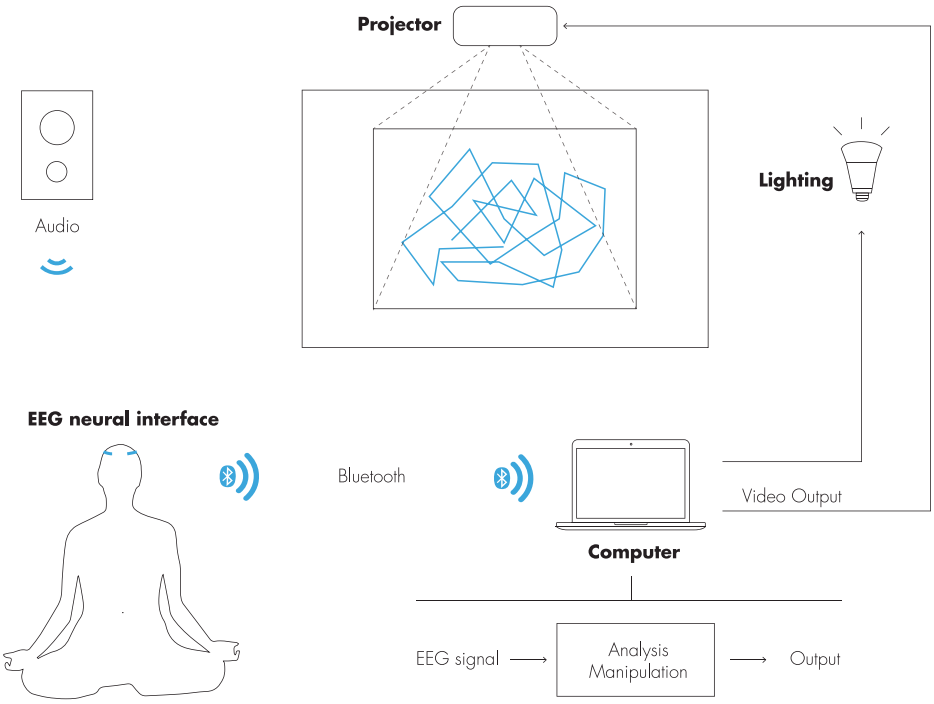

Figure 3. Initial concept of the installation

concept of the visual form

Determining a compelling visual concept was essential to achieving the goal of the project of creating a meaningful and visually engaging user experience.

After spending an extensive amount of time on the research, the mandala was selected to be the most appropriate visual form to visually represent the mind. Mandala's profound philosophical meaning and purpose fully match the concept of the project, creating a meaningful visual experience.

Tibetan Buddhism is considered to be the most visually rich Buddhist practice. It is widely known for its extensive repertoire of symbols, deities, and mandalas. The Kalachakra Mandala[1] is considered as one of the most complex mandalas in Tibetan Buddhism.

The visual form for the final installation is an abstract mandala, designed following traditional method of constructing the Kalachakra Mandala. The principle of polarity and unity, fundamental in both Jung's model and Buddhist philosophy, were taken into consideration during the design process.

1 Martin Brauen. *The Mandala: Sacred Circle in Tibetan Buddhism*. Boston; [New York]: Shambhala ; Distributed in the U.S. by Random House, 1998.

process

methodology

Since the project's goal is to create visually engaging experience in useful ways, it can be categorized as an art and design project. Thus both art and design methodological approaches are used.

areas of interest

This project is the integration of research and study in the following areas (Fig. 4).

human component

The research on cognitive science and philosophy was essential to determine meaningful content.

design component

The research on basic design, color theory, time-based design, and digital art were essential to devise an engaging visual form and overall aesthetic concept.

technology component

The knowledge of hardware and software tools was necessary for the implementation of the project.

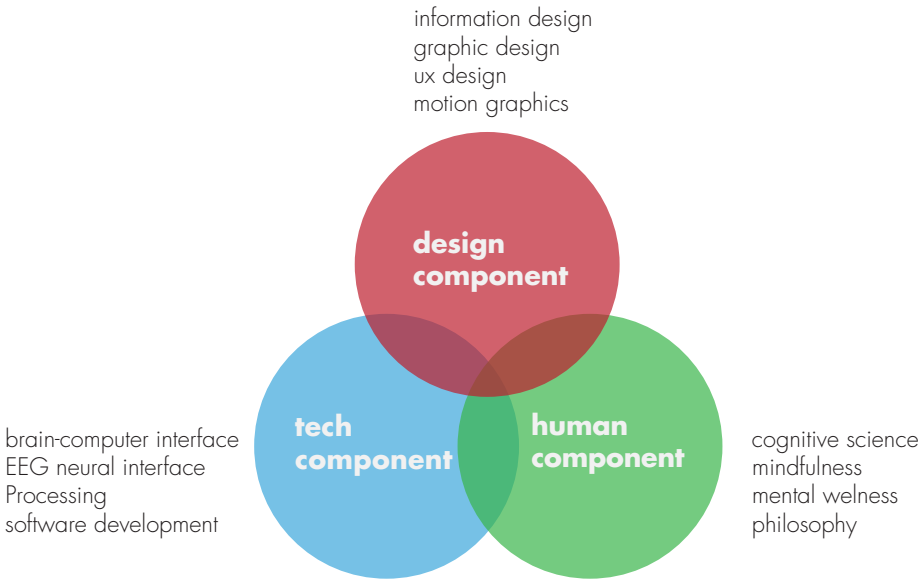

Figure 4. Diagram shows three areas required to implement the project

design process

visual form: abstract mandala

The abstract mandala for the interactive installation was based on the construction and structure of the Kalachakra Mandala.

The Kalachakra Mandala is constructed during the Kalachakra ritual, and it is considered as one of the most complex mandalas in Tibetan Buddhism. It is a two-dimensional representation of the three-dimensional five-story palace of Kalachakra[1]. It contains 722 deities represented by symbols. The basic colors are white, black, blue, red, yellow, and green. Each of the last four colors have three shades dark, medium, and light.

Structurally, the Kalachakra Mandala consists of outer and inner parts. The outer part consists of six concentric circles or discs, symbolically represent the universe or outer cosmos, namely: wisdom, space, air, water, fire and earth. The inner part consists of the body, speech, and mind levels that have structural correspondence to human body[2]. The mind level is further divided into sub-level of great bliss and deep awareness.

The following is the step-by-step process of creating the abstract mandala.

grid and structure

The design process started by building a grid system following the construction method used during the Kalachakra ritual[3]. The ritual starts setting the center point where two perpendicular lines cross. The lines extend until the outer perimeter. The distance between the center point and the outer perimeter is divided into 13 equal units (basic unit is called gho-tsed in Tibetan) making it 26-column grid both horizontal and vertical (Fig. 5). Additionally, each column

1 Martin Brauen. *The Mandala: Sacred Circle in Tibetan Buddhism*. Boston; [New York]: Shambhala ; Distributed in the U.S. by Random House, 1998, 71.

2 Ibid., 52.

3 Barry Bryant. *The Wheel of Time Sand Mandala: Visual Scripture of Tibetan Buddhism*. 2nd ed. Ithica, N.Y: Snow Lion Publications, 2003, 183-192.

is divided into 6 sub-divisions. The purpose of having sub-divisions is to have smaller scale to build the inner parts of the mandala, which requires more accurate measurements.

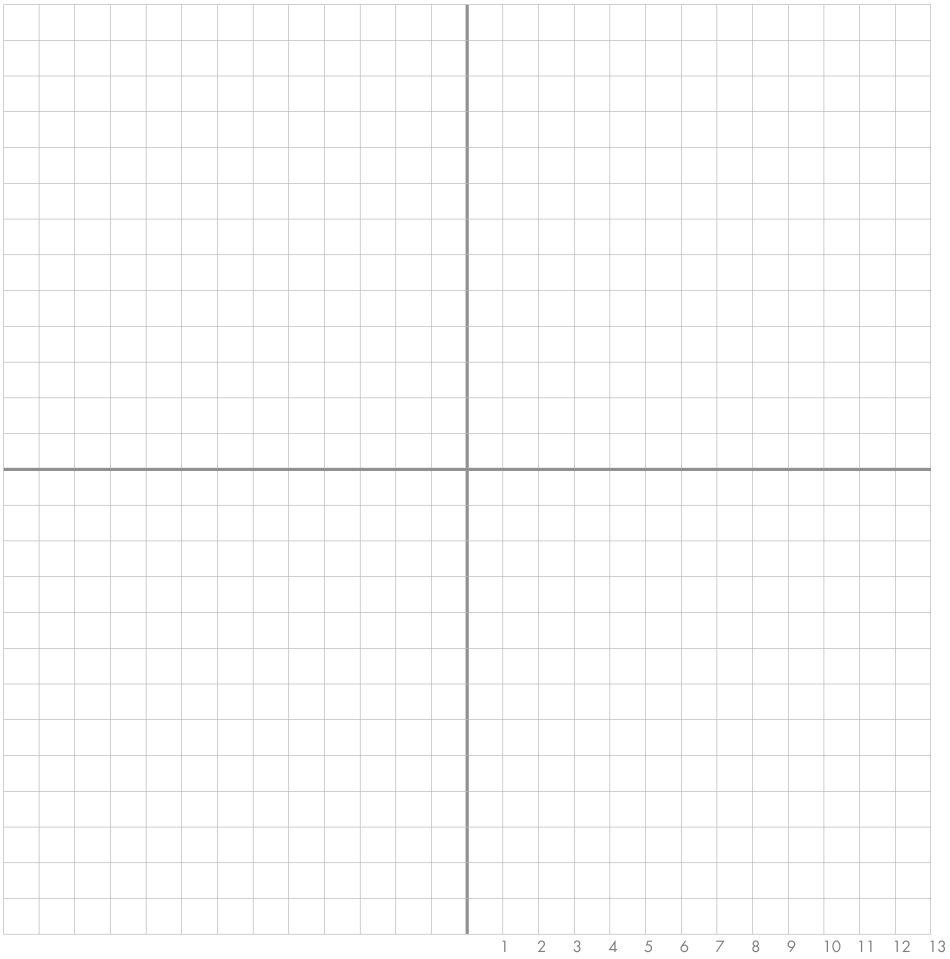

Figure 5. 26 x 26 grid. Sub-divisions are not shown

The next step is to add diagonal lines that intersect at the center point (Fig. 6).

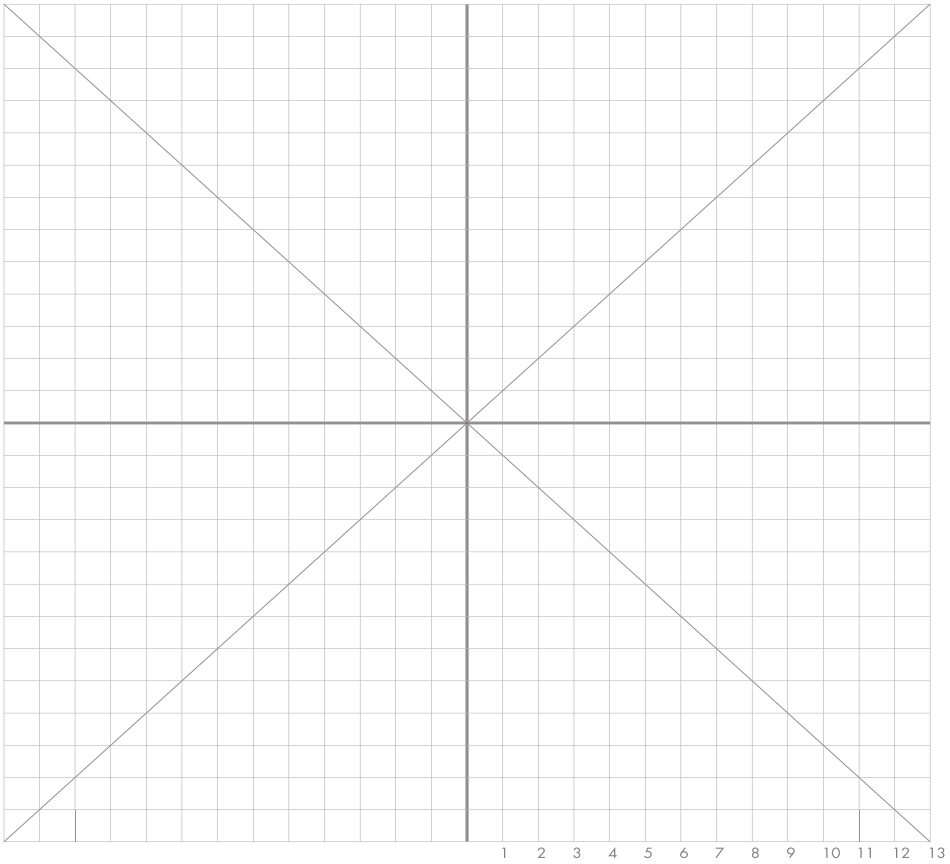

Figure 6. Adding 45 degree diagonal lines

The creation of the mandala starts from the inner-most part and continues outwards in the order of the mind, speech and body levels. The construction starts from the mind level, the inner-most level (Fig. 7). The visual elements are accurately aligned to the sub-division grid.

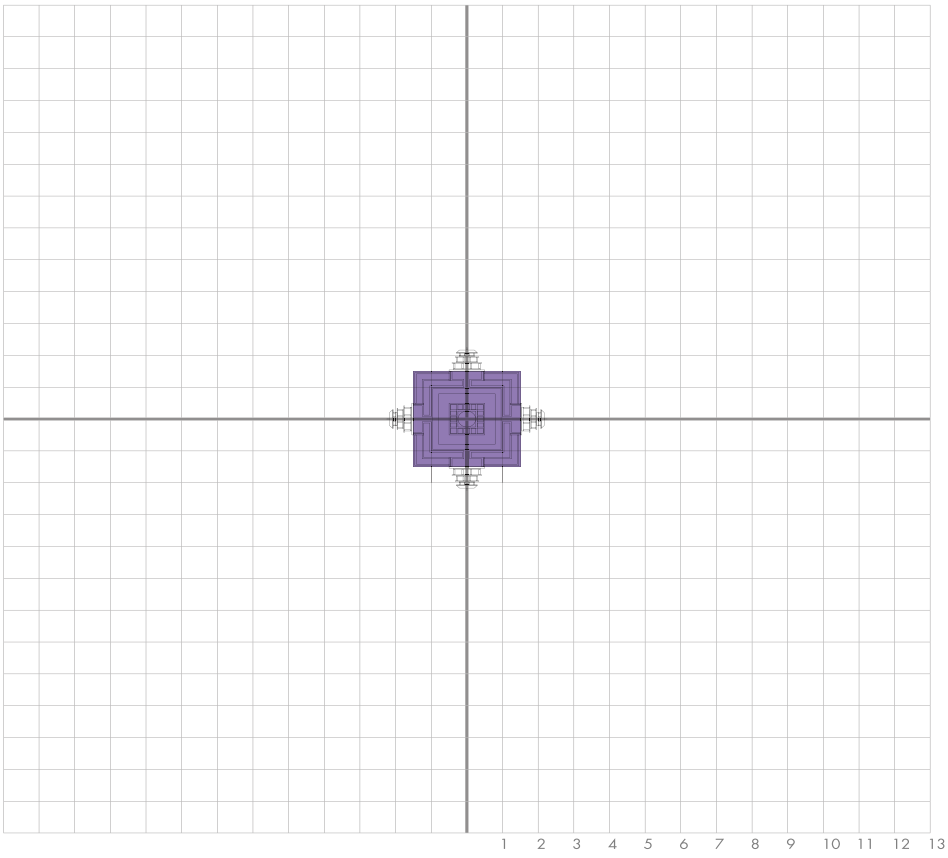

Figure 7. The mind level

The speech level is constructed after the mind level (Fig. 8).

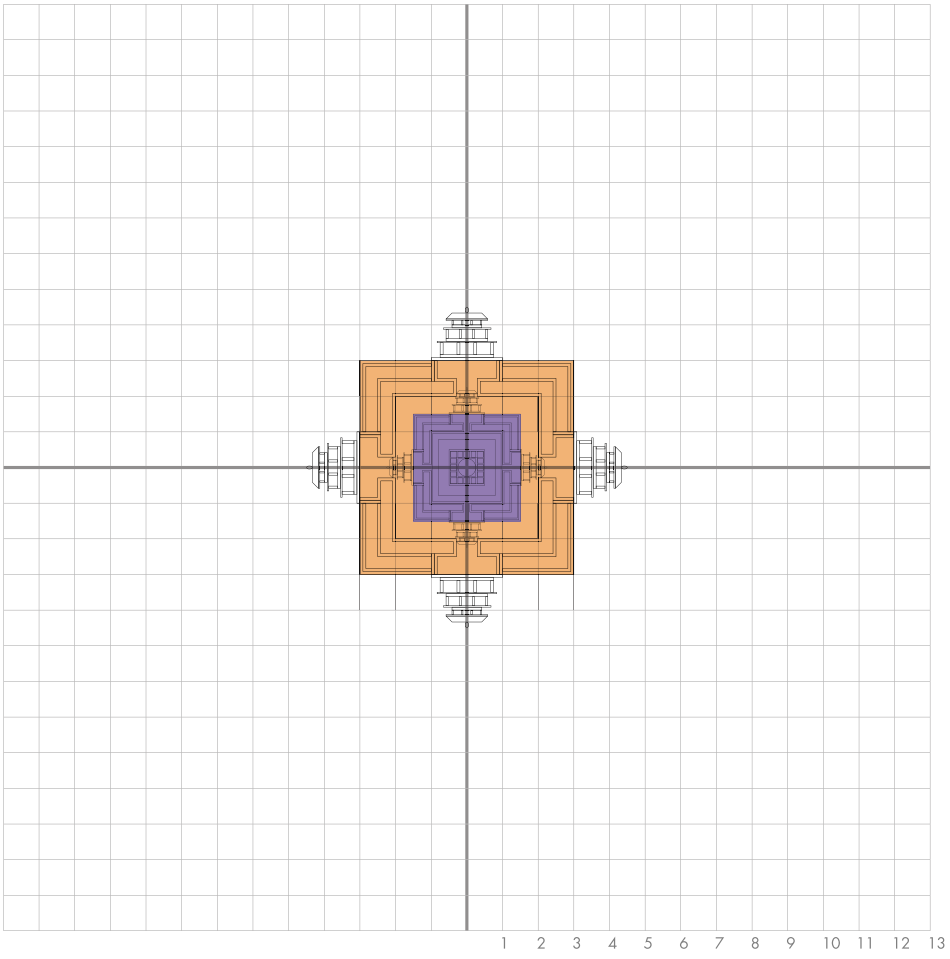

Figure 8. The speech level

The outer most level of the inner part of the mandala is the body level (Fig. 9).

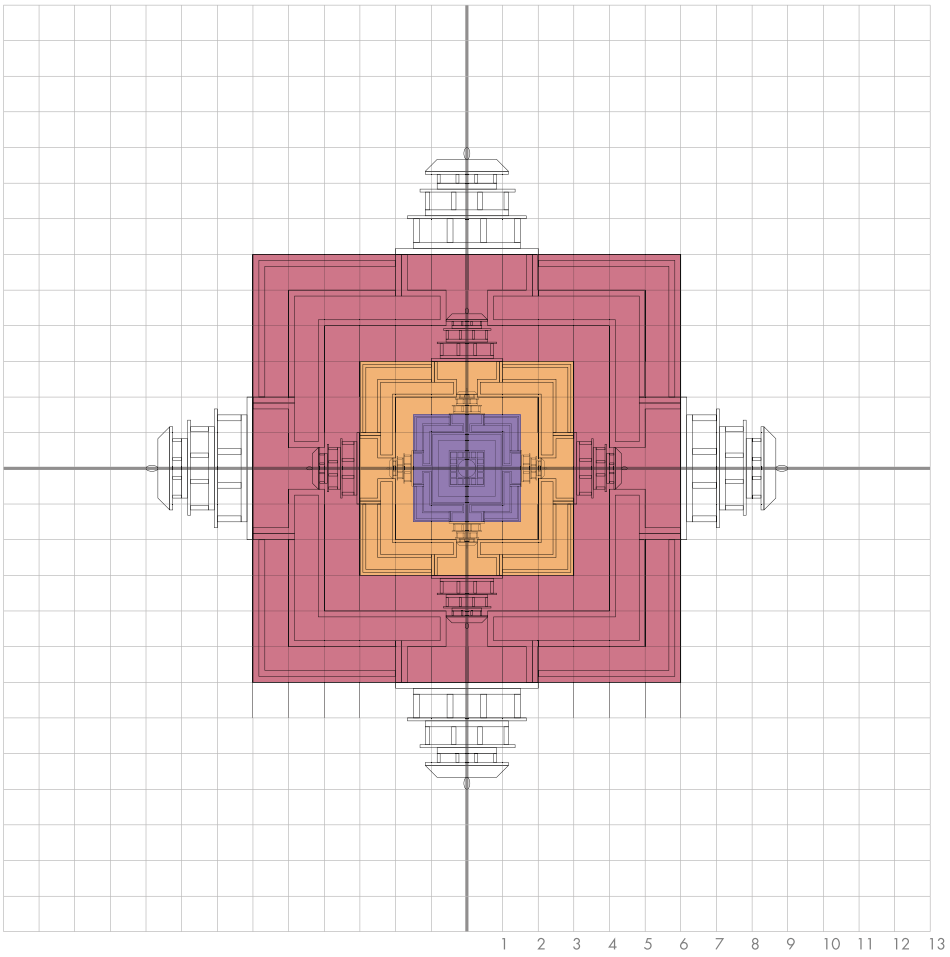

Figure 9. The body level

Then the outer part of the mandala, which consists of six outer rings, is built. These outer rings symbolically represent the universe or outer cosmos, namely: wisdom, space, air, water, fire and earth (Fig. 10).

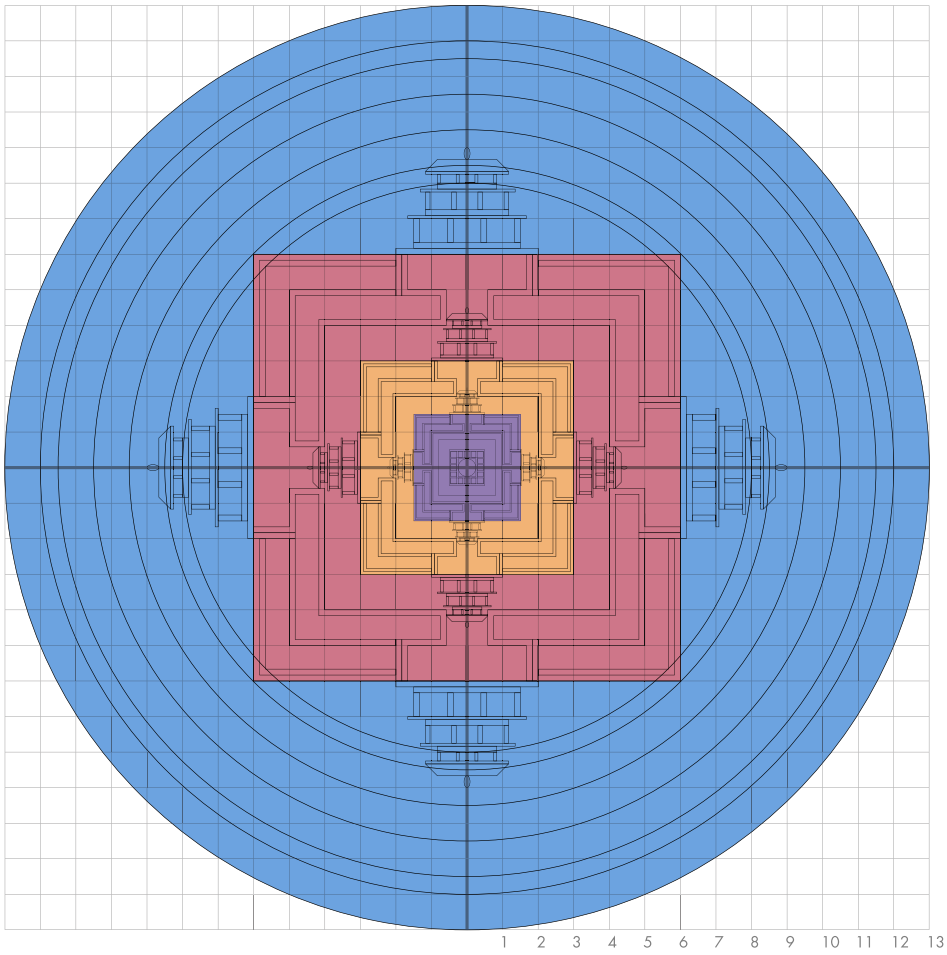

Figure 10. The completed grid structure

design variations

Traditionally, after constructing the grid and basic structure, various symbols representing the deities and elements are added with color and various decorations. Similarly, the process of designing abstract mandala continued by creating several different visual form variations. The early attempts of using a traditional color palette and shapes of the Kalachakra Mandala resulted in a convoluted form (Fig. 11). Therefore, I restricted my design variations to meet following conditions:

- use basic geometric shapes - to reduce complexity
- avoid using too many colors - to reduce complexity
- align to the grid – to follow the mandala's structure
- lead eyes to the center – to follow the mandala's meaning and purpose

Figure 11. Variation 1 uses traditional color palette of the Kalachakra Mandala

Figure 12. Variation 2 uses simplified color palette with basic geometric shapes

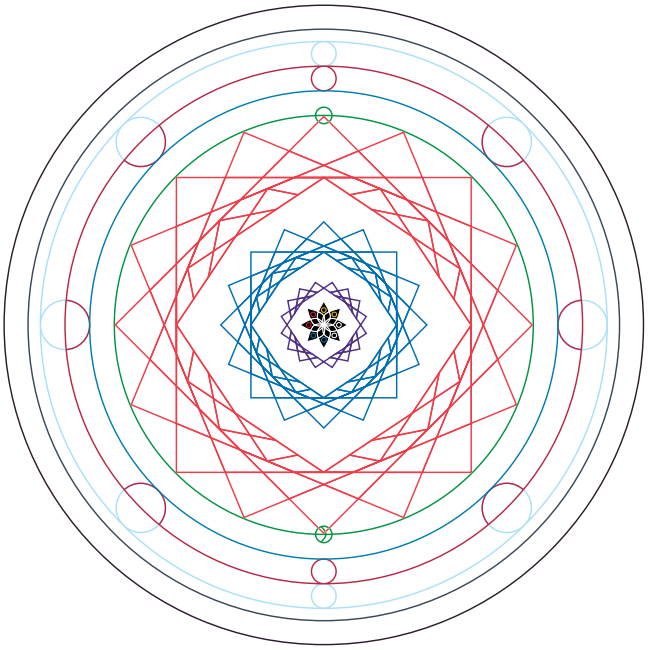

Figure 13. Variation 3 uses the basic geometric shapes with strokes. The lotus symbol referenced from the Kalachakra Mandala is placed in the center

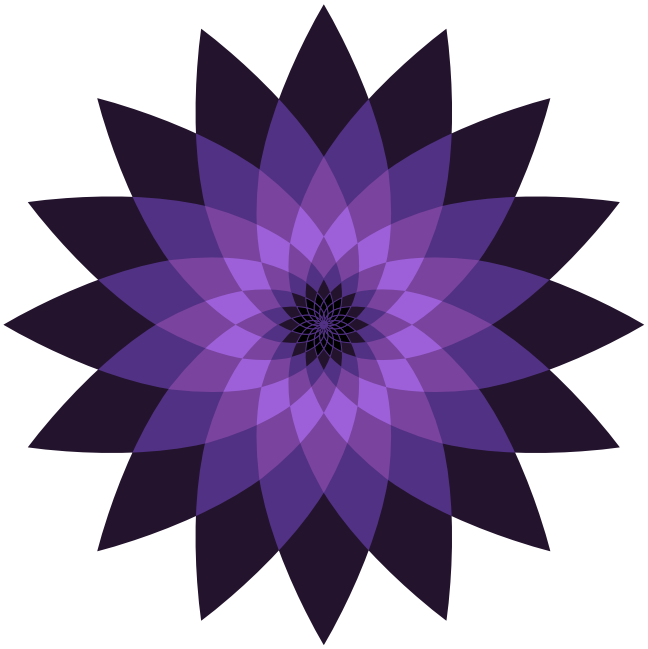

Figure 14. Variation 4 is the lotus shaped mandala using basic shapes with simplified color palette

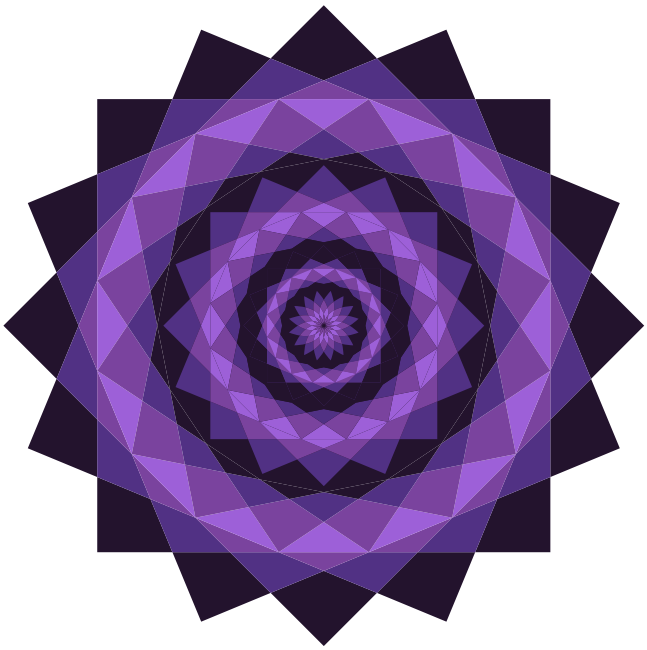

Figure 15. Variation 5 is the blend of lotus and basic geometric shapes

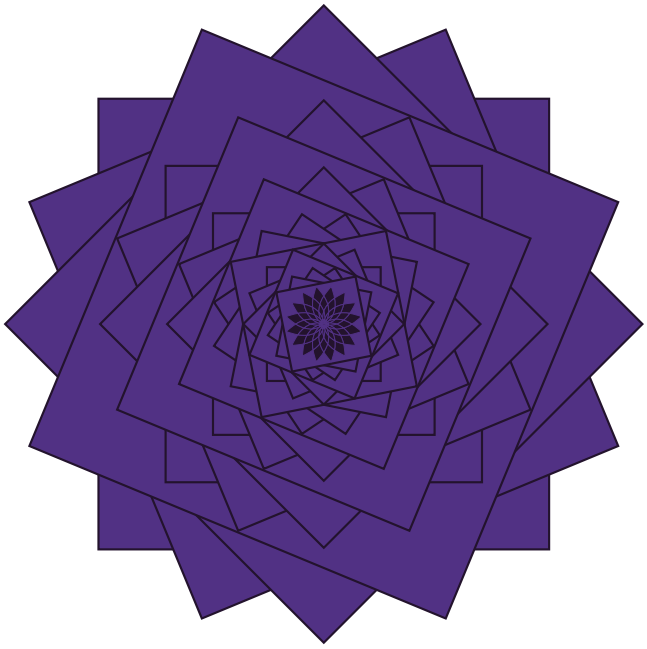

Figure 16. Variation 6 uses overlapping shapes

In the end, variation 3 and 4 were chosen because of their effectiveness of expressing depth, which pulls attention into the center (Fig. 17, 18). Then to determine the final visual form, their effectiveness in motion was compared by creating short motion videos using After Effects.

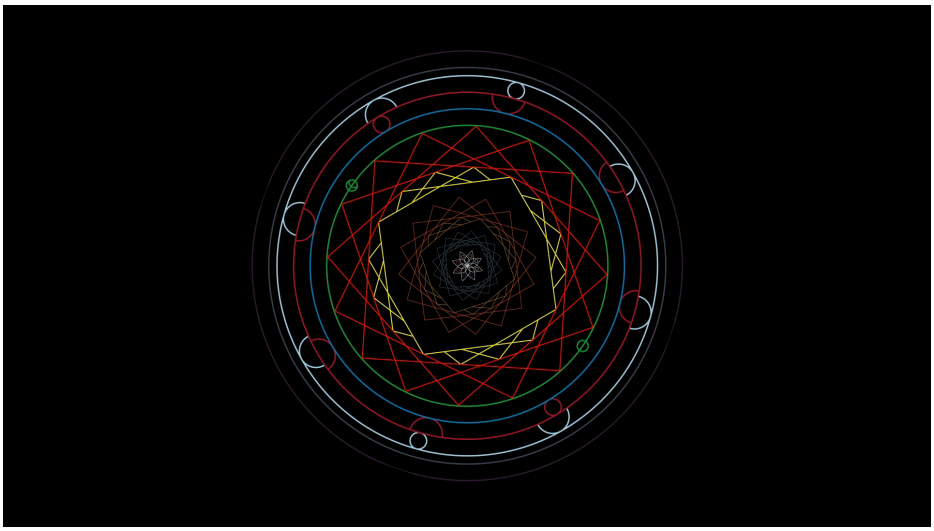

Figure 17. Frame capture from the animation of variation 3

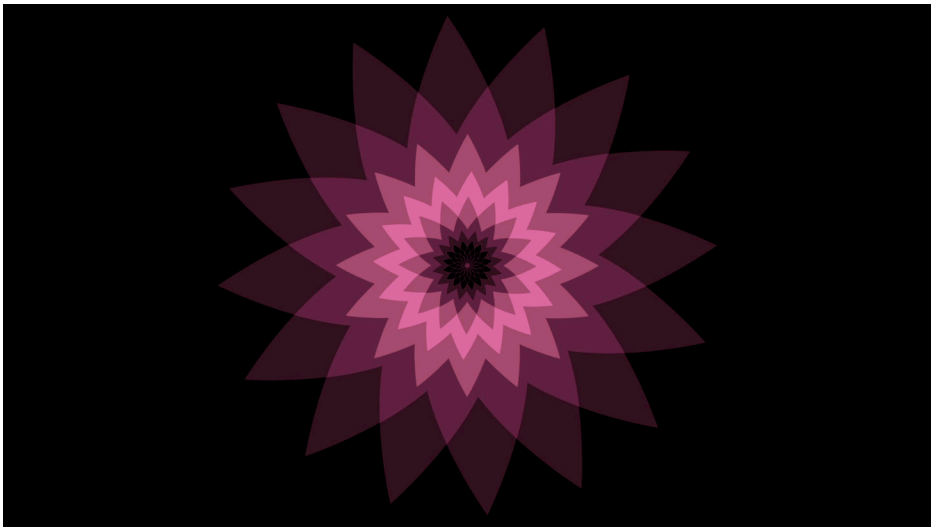

Figure 18. Frame capture from the animation of variation 4

After comparing the motion videos, the variation 3 was selected as a final visual form (Fig. 19). The distinct rotation speed of shapes produced random line intersections that created intriguing new shapes. Taking into account the number of brain wave frequency bands and their data input, variation 3 was further refined, replacing the inner part with a group of six overlapping rectangular shapes that behave independently (Fig. 20, 21). Each group consists of four basic rectangular shapes.

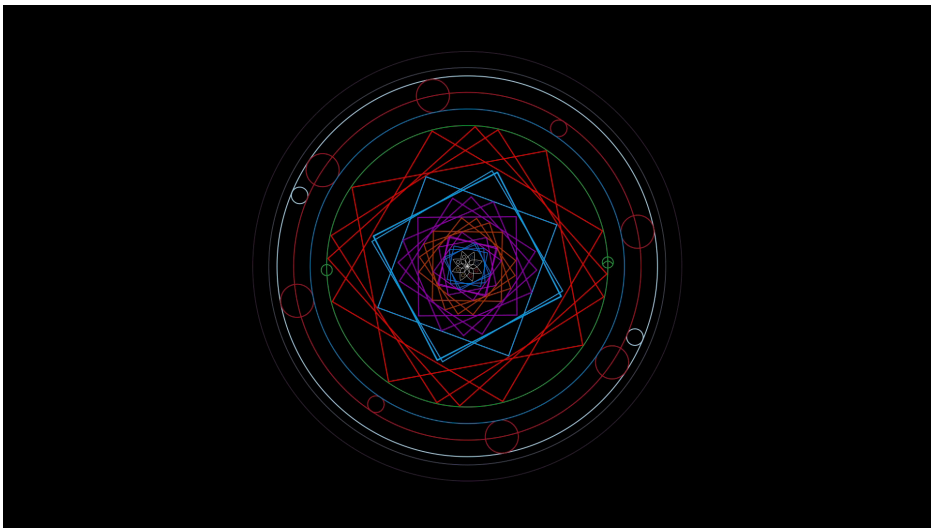

Figure 19. Frame capture from the animation of the final visual form

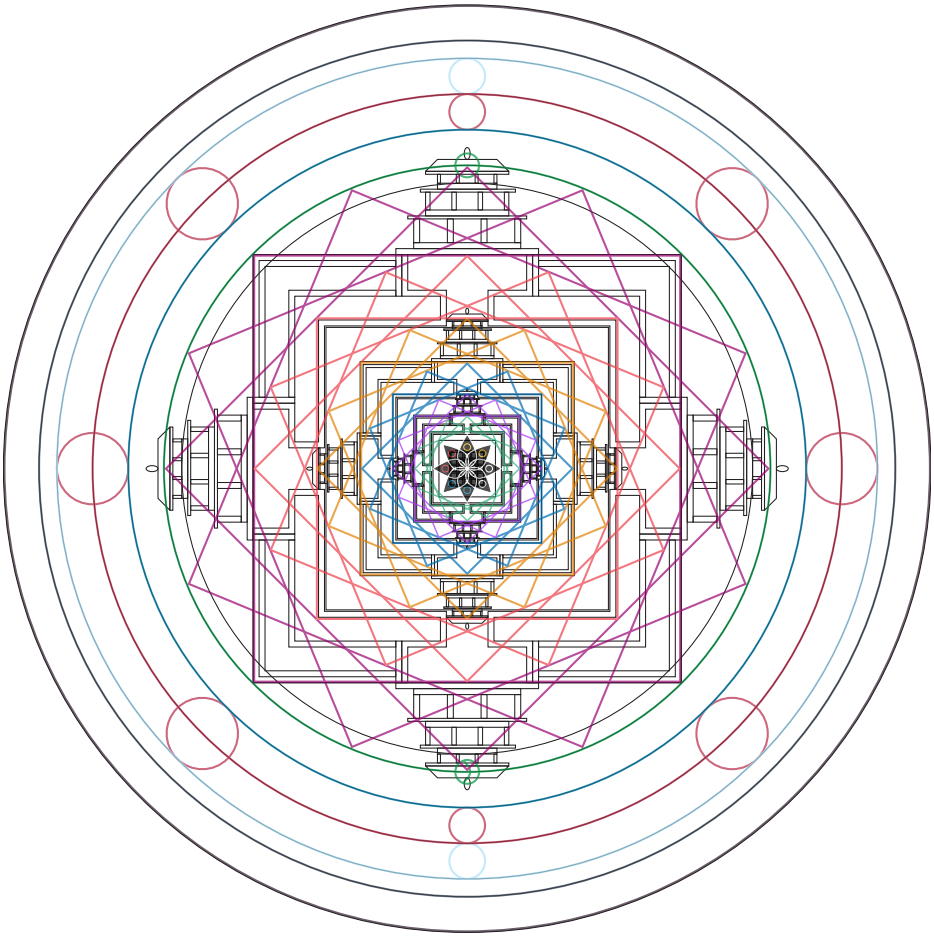

Figure 20. Final visual form overlaid on top of the grid

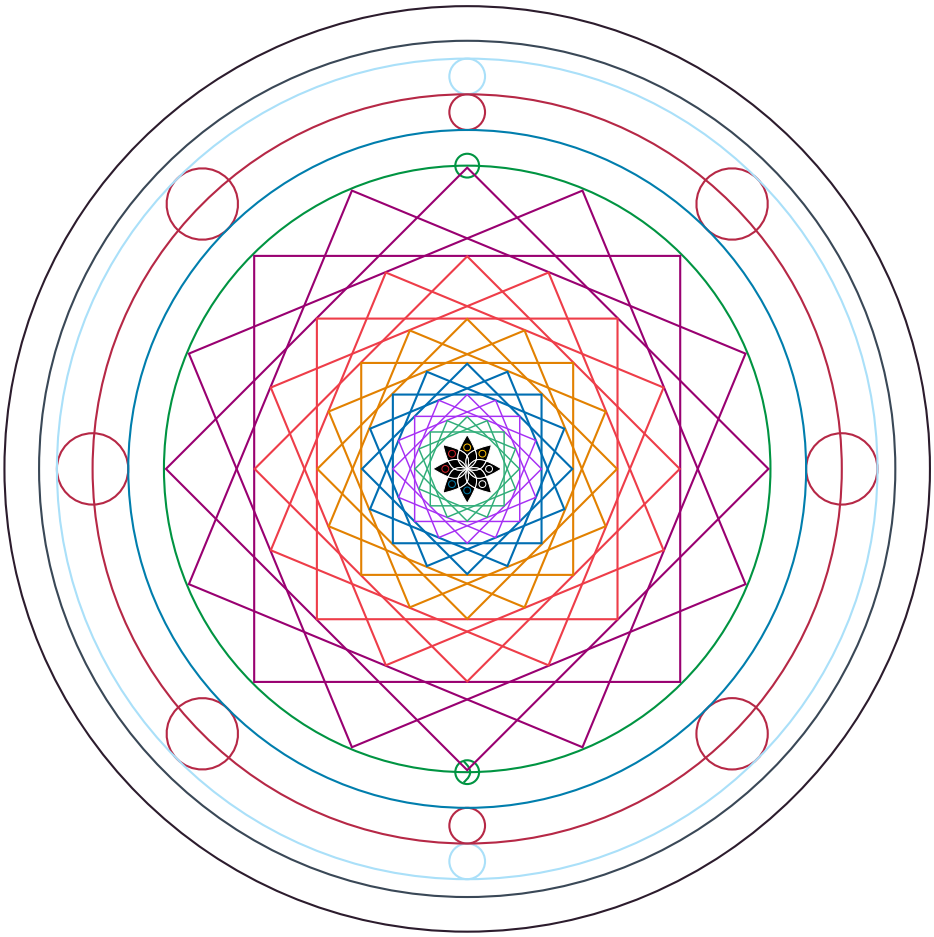

Figure 21. Final visual form

interactive and time-based transformation

The visual elements of the abstract mandala form change their *rotation speed* and *color (hue, saturation, brightness)* according to received brain wave signal data. The intensity of the change is determined by a signal value.

As previously mentioned, signals have different frequency bands. Each frequency band commonly associated with different mental states (Fig. 22).

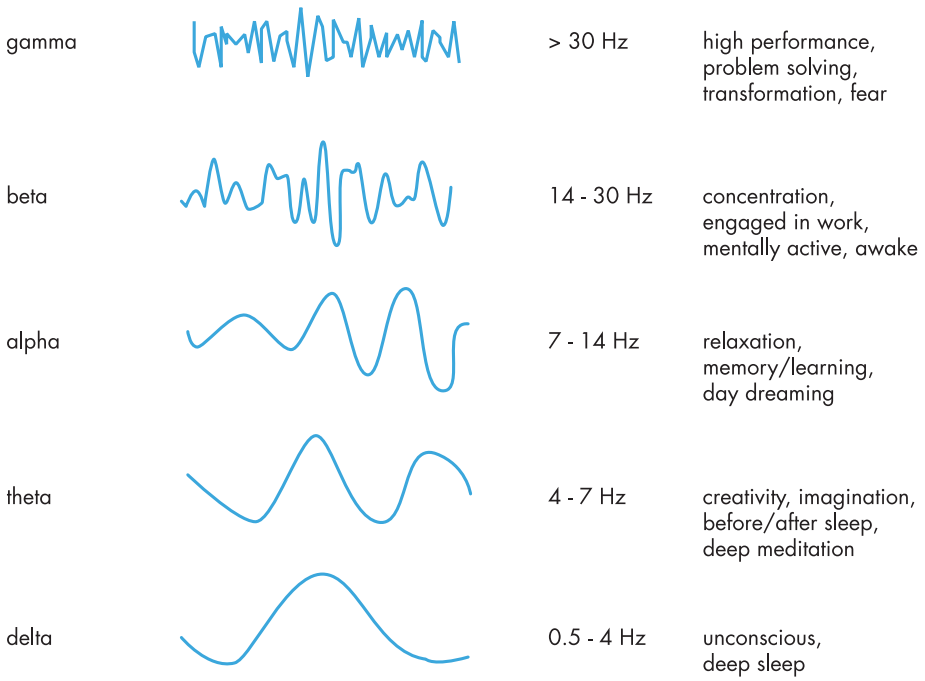

Figure 22. Brain wave signals correspond to different mental states

The following table and figure show a relationship between the visual elements and brain wave frequency bands.

Frequency Bands	Level	Element manipulated
Delta	1-4Hz	Lotus, inner and outer mind levels
Theta	5-8Hz	Inner speech level
Alpha	9-13Hz	Outer speech level
Beta	12-30Hz	Inner body level
Gamma	30-50Hz	Outer body level
Alpha, Beta, Gamma		Outer level rings

Table 1. Brain wave frequency bands' association with different visual elements

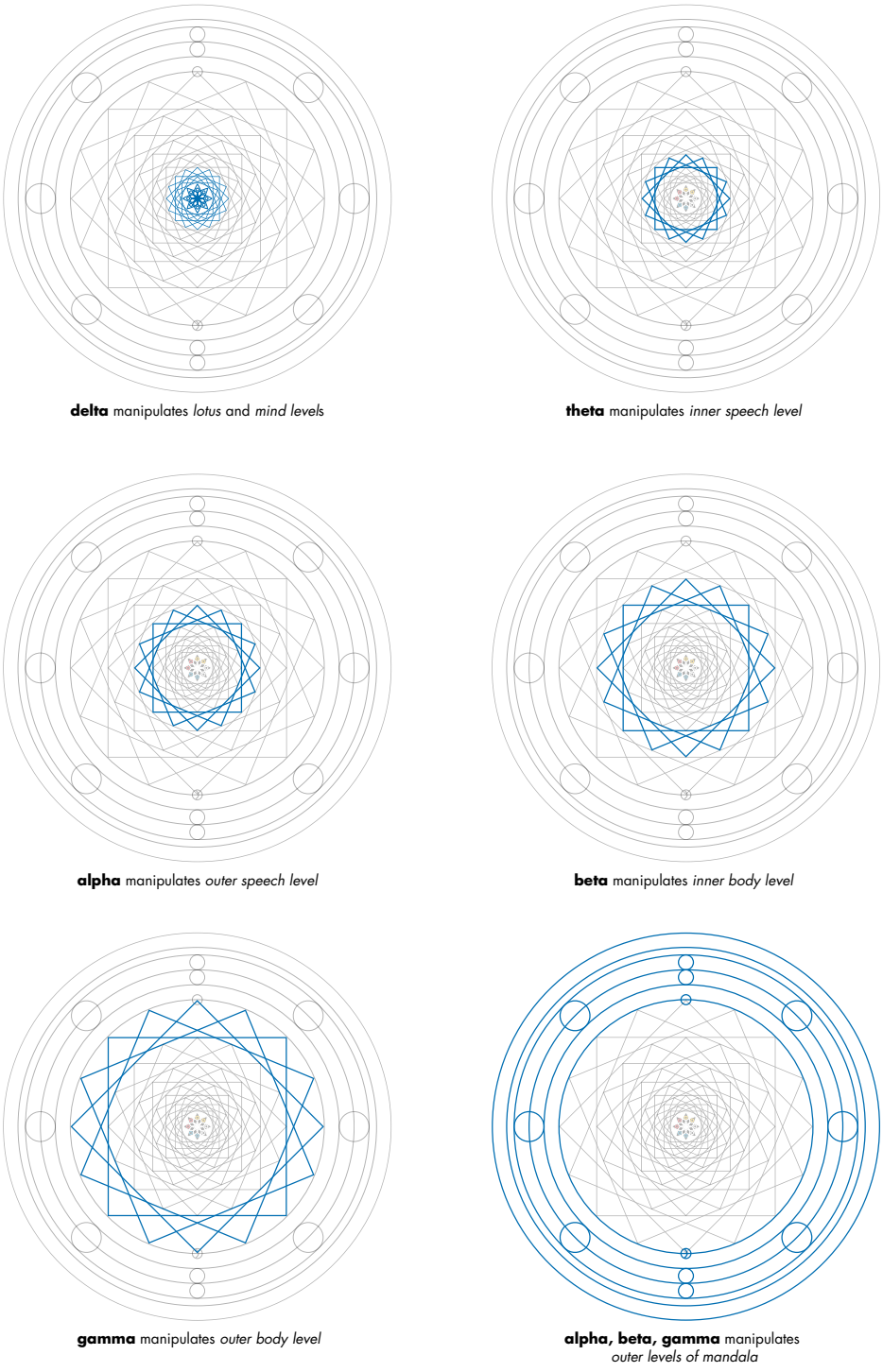

Figure 23. The visual elements are manipulated by different frequency band values

audio

The audio was one of the crucial components of the installation. The audio was played from the *Brain.fm*[1], a web-based algorithmically generated engine specifically designed to create background music for studying, sleeping, or relaxation. It did not have a direct influence on the visual form; it was only used for intensifying the user experience. However, its effect on user's brain activity was observed.

In order to test the installation's effectiveness as an audio-visual projection for live performances, the vocal-less music tracks were pre-selected and played during the testing sessions.

lighting

The wireless light was another component of the installation. Three parameters of the light; hue, saturation and brightness, were manipulated based on brain wave signal data values.

1 "Brain.fm: Music to Improve Focus, Meditation & Sleep." Accessed April 2, 2016. https://www.brain.fm/.

implementation

The project implementation took the form of an interactive installation.

installation components

The installation was setup in a spacious dark room with stereo speakers, computer, projector, screen, digital cameras, and lights. The participant put on the EEG headband and sat on the chair located in the middle of the room. The participant observed the visual output projected on the screen while listening to the audio (Fig. 24).

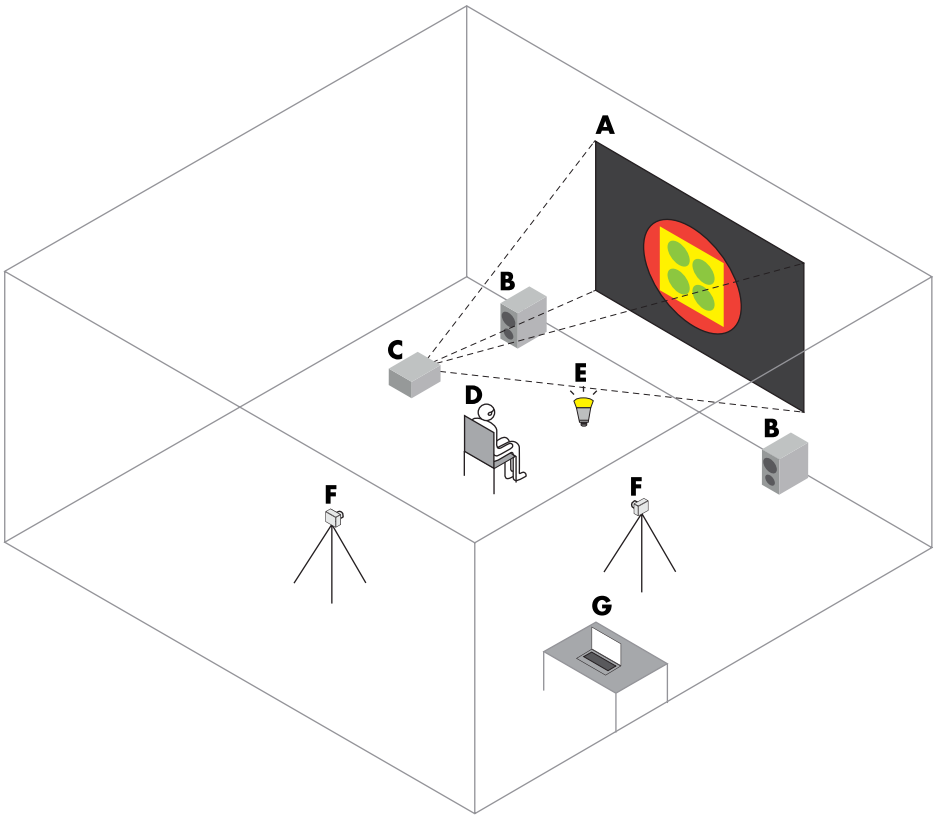

Figure 24. Prospective setup of the installation. A: screen, B: stereo speaker, C: projector, D: participant, E: light, F: digital cameras for video recording, G: computer and a table

tools and equipments

There are several different consumer and research grade EEG headband devices available in the market. After comparing several different devices, *Muse* headband was selected because of its ease of use and features that met requirements of the project. For the wireless light, Philips Hue Go was selected because of its ability to communicate through HTTP based API which can be implemented through Processing's network library.

The following is the list of hardware and software tools used for the implementation:

Hardware

- Muse EEG headband
- Wireless Light (1)
- Stereo speaker
- Digital cameras (2)
- Computer
- Projector
- Screen

Software

- MuseIO device driver
- MuseLab
- Processing
- oscP5 library for Processing
- controlP5 library for Processing

EEG device and available data

Muse headband tracks brain activity through seven sensors – two on the forehead, two behind ears, and three forehead reference sensors (Fig. 25, 26).

Figure 25. The Muse headband by Interaxon

Muse comes with the software development kit (SDK). It gives access to a variety of data including the raw EEG and computed data. Computed data is filtered and computed from raw EEG values. It is run through a series of computations to make the data easier to use without the complexity of understanding signal processing, neuroscience, or machine learning. This computed data could be accessed through Muse Elements[1]. It can be described as an algorithm and signal processing pack. SDK has configuration presets[2] that can change the device's settings and configurations based on specific needs. For this project, preset 14 was chosen (Fig. 26), because it provides accelerometer, compression, error data and other helpful features.

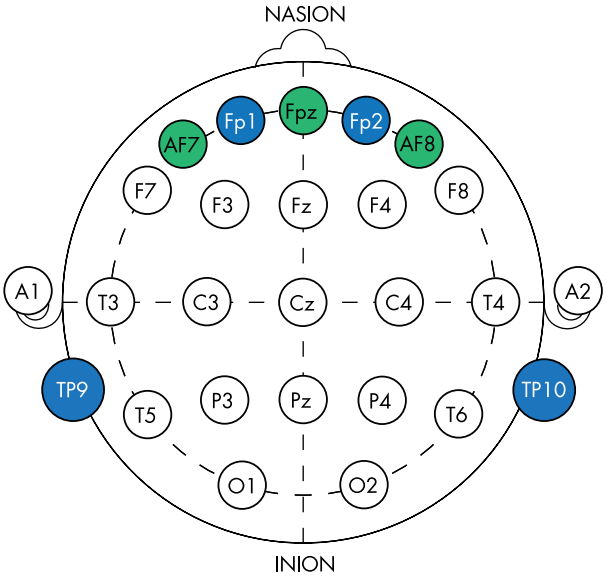

Figure 26. Muse EEG headband sensor locations shown on the International 10–20 system for EEG electrode placement. At preset 14, the device will detect brain activity on TP9, Fp1, Fp2, TP10 electrodes.

Muse Elements provides several different types of values computed from the raw EEG data. The simplest to work with is "Band Power Session Scores" data type. It gives values between 0 and 1 by comparing the user's current band power value to an average of their recent historical values. The following table shows detailed specifications:

1 "Available Data." Muse Developers. Accessed March 9, 2016. http://developer.choosemuse.com/research-tools/available-data.

2 "Headband Configuration Presets." Muse Developers. Accessed March 9, 2016. http://developer.choosemuse.com/hardware-firmware/headband-configuration-presets.

MuseIO Paths	/muse/elements/delta_session_score /muse/elements/theta_session_score /muse/elements/alpha_session_score /muse/elements/beta_session_score /muse/elements/gamma_session_score	
Units	Unitless	
Datatype	floats	
Transmission frequency	10 Hz	
OSC Data Format	Four channels for each band power: ffff	
Frequency Ranges	**Name**	**Frequency Range**
	Delta Session Score	1-4Hz
	Theta Session Score	5-8Hz
	Alpha Session Score	9-13Hz
	Beta Session Score	12-30Hz
	Gamma Session Score	30-50Hz

Table 2. The specification of "Band Power Session Scores" data type

lighting device

Philips Hue Go portable light device was used as a lighting source (Fig. 27). The color of the device can be controlled by changing hue, saturation and brightness variables, which can be updated through HTTP based API[3]. Philips Hue Bridge is a hub required to connect to Philips Hue Go (Fig. 28).

Figure 27. Philips Hue Go wireless light

Figure 28. Philips Hue Bridge hub

3 "Philips Hue API." Accessed April 12, 2016. http://www.developers.meethue.com/.

The figure shows the flow of the data stream between devices (Fig. 29). The signal stream was transmitted from the headband to the computer via Bluetooth using MuseIO driver, which forwarded the signal to OSC protocol. In the Processing environment, the signal stream was received using oscP5 library and was available as numerical data.

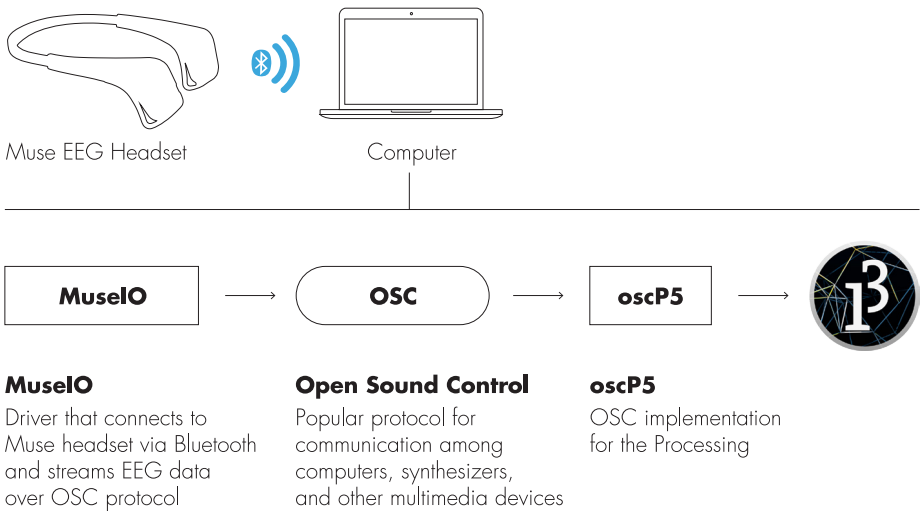

Figure 29. Software components required to send brain wave signal stream into Processing

Once the signal stream was received in the Processing environment, it was analyzed and passed as an input parameter to the program every preset time interval, manipulating visual output and the lighting of the room. The color and rotation speed were altered depending on the values at each time interval (Fig. 30).

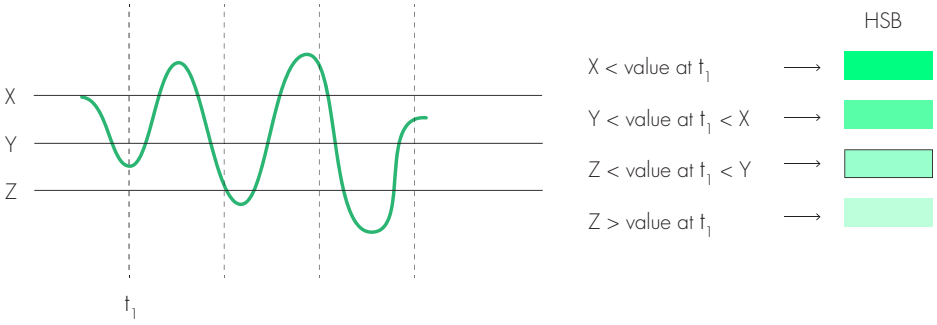

Figure 30. Example of color manipulation according to the signal value at the time point t_1

receiving EEG data

The following is the step-by-step process of connecting and setting up Muse EEG neural interface to send data stream using OSC protocol via Bluetooth and receive it in the Processing environment.

- Pair Muse EEG headband with the computer via Bluetooth connection.
- Connect to the MuseIO and start streaming the data using desired settings.
  `muse-io --device DeviceName --osc osc.udp://localhost:5000`
- Receive data stream using oscP5 library in the Processing environment.
  `oscP5client = new OscP5(this, 5000, OscP5.UDP);`
- Use oscEvent function to receive and store the data from OSC stream.

```
void oscEvent(OscMessage msg) {
    if(msg.checkAddrPattern("/muse/elements/delta_session_score")==true){
        deltaOsc[0] = int(msg.get(0).floatValue()*100);
        deltaOsc[1] = int(msg.get(1).floatValue()*100);
        deltaOsc[2] = int(msg.get(2).floatValue()*100);
        deltaOsc[3] = int(msg.get(3).floatValue()*100);
    }
}
```

first prototype

The first basic prototype was developed to show proof of concept. It was a Processing sketch that drew vertical lines every 1/6 of a second. The intensity of each vertical line's color (saturation and brightness) was determined according to the alpha wave signal value received. Assuming alpha wave values change according to the user's state of focus, the program visually represented the user's focused state with dark lines, and unfocused state with red lines (Fig. 31).

Figure 31. Visual output from the first prototype

final prototype

The final two prototypes were built as Processing sketches. The first prototype was to evaluate the potential for meditation and therapy applications; the second prototype was to evaluate the potential use for live performances.

prototype 1

Filename	Function
Prototype.pde	Main sketch file. It initializes parameters and variables in the setup() function, and continuously draws visual elements every frame in the draw() function. Drawing parameters are changed based on the incoming brain wave signal data and retrieved in the oscEvent() function. It also includes frequently used functions.
MandalaElement.pde	Contains class MandalaElement, which includes common methods and variables to control the visual elements of the Mandala form.
PhilipsHue.pde	Contains class PhilipsHue, which includes common methods and variables needed to control Philips Hue light. Can be used with multiple Philips Hue lights.
Mandala_Stroke.svg	Scalable Vector Graphics (SVG) graphic image file, which contains elements of Mandala form. It is imported in the main sketch file.

Table 3. The Processing sketch files developed for prototype 1

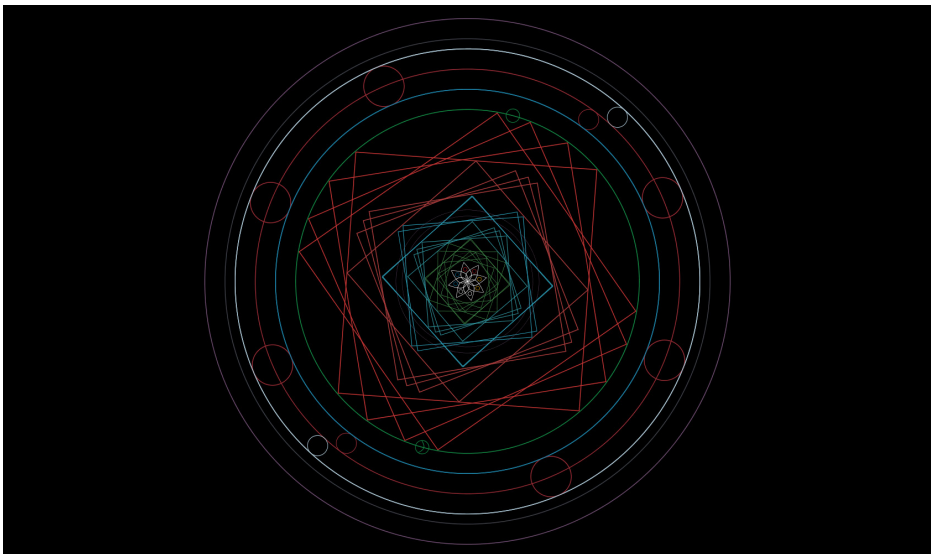

Figure 32. The screen capture from Processing sketch for prototype 1

prototype 2

Filename	Function
Prototype2.pde	Main sketch file. It initializes parameters and variables in the setup() function, and continuosly draws visual elements every frame in the draw() function. Drawing parameters are changed based on the incoming brain wave signal data and retrieved in the oscEvent() function. It also includes frequently used common functions.
GenElement.pde	Contains class GenElement which includes common methods and variables to control visual elements of the visual form. In addition to brain wave signal data, it uses noise() function to create random effects on visual elements.
PhilipsHue.pde	Contains class PhilipsHue which includes common methods and variables needed to control Philips Hue light. Can be used with multiple Philips Hue lights.

Table 4. The Processing sketch files developed for prototype 2

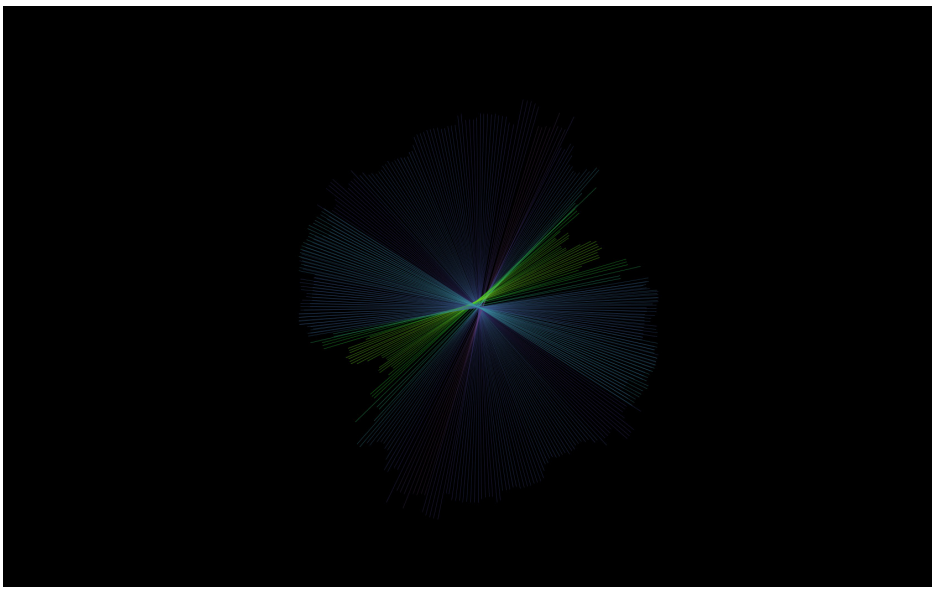

Figure 33. Screen capture from Processing sketch for prototype 2

final installation setup

Figure 34. Two cameras were placed behind and on the right side of the chair. Lamp was placed to light the face of the user during the recording

Figure 35. View from the front

Figure 36. Main computer where software tools were setup and executed

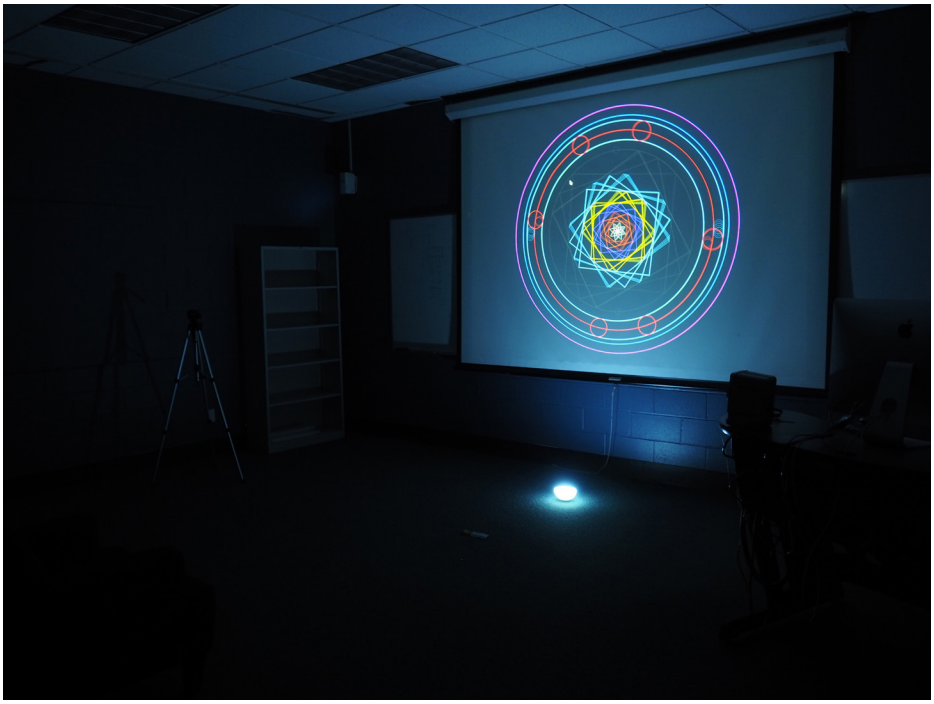

Figure 37. Philips Hue Light was placed in front of the couch. Room lights were turned off

evaluation

evaluation method

Interactive installation shares many common qualities with traditional artwork; both have physical construction and create experiences for the audience. However, it differs from traditional artwork by encouraging users to become a part of the artwork by interacting with it.

Considering the primary goal of the project was to create meaningful and visually engaging user experience, assessing the user experience is the main objective of the evaluation.

Traditional Human Computer Interaction evaluation methods measure usability of the software or digital system. However they often fail when it comes to evaluation of interactive digital installations.

The research on evaluation methods used on similar interactive projects revealed that the combination of qualitative methods of observation, data recording and interview is the optimal way to evaluate user experience. In order to explore feasible quantitative methods for future evaluation, brain wave activity signal data were recorded and analyzed as well.

qualitative method

The qualitative method consists of observation, data recording (video recording), interviews and written questionnaires.

- Observation - observation during the session
- Data recording - video recording of the session
- Interview - short interview after the session
- Questionnaire - one page written questionnaire

quantitative method

The brain wave signal data was recorded before and at the end of the session using MuseLab tool. The recorded data was analyzed and summarized.

testing room

The installation was setup in room 1315 in James E. Booth Hall at the Rochester Institute of Technology (RIT). The room was setup to let participants feel the physical space around them. A chair was placed in the middle of the room where the participant sat comfortably during the session. The two cameras attached to tripods were placed in the back and on the side of the chair to capture both the screen and the participant's face. The lights in the room were completely turned off, except for the Philips Hue Go light and a lamp near the couch. The audio was played through surround and two front stereo speakers.

testing process

1. The testing session started by greeting a participant, and followed with a brief explanation about the project. I asked the participant's permission to record their brain activity, session, and interview to submit as part of the thesis documentation.

2. After pairing the headset via Bluetooth, I helped the participant to put on the EEG headband.

3. Then MuseIO tool was run to send incoming data from the headset via open sound protocol on localhost via UDP port 5000. To receive data, MuseLab was configured to listen on UDP port 5000, and forward them to localhost UDP port 6000. This forwarding setting was necessary to simultaneously record brain activity and run the prototype (Processing sketch).

4. After confirming the successful connection, the headset sensors were checked to see whether they were detecting signals properly through MuseLab tool (Fig. 38).

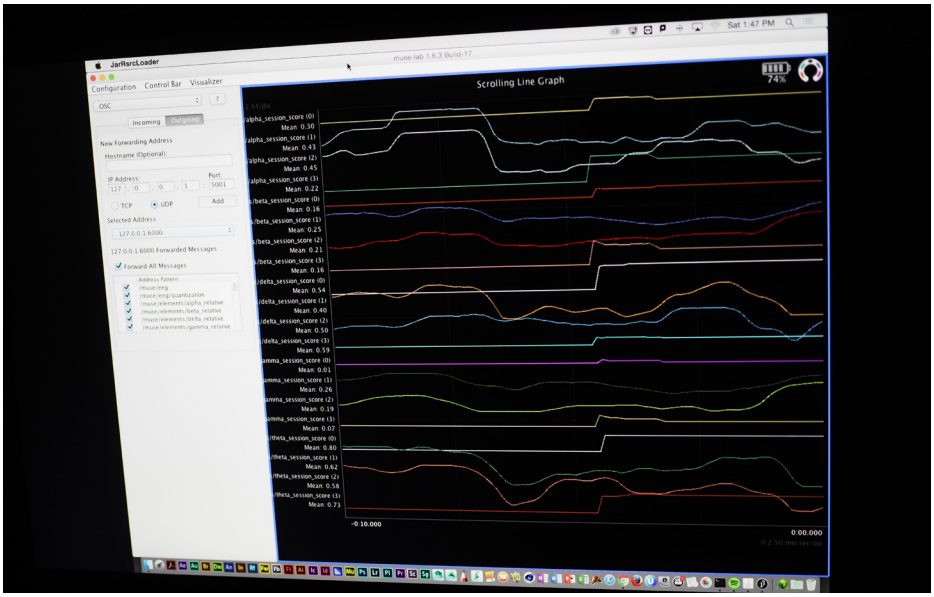

Figure 38. MuseLab tool

5. The first part of the session started by recording the participant's brain activity for about two minutes after detecting the incoming signals. The purpose was to compare quantitative data of the participant's brain activity before and during the first part of the session.

6. After stopping the first brain activity recording, the new brain activity recording was started. The cameras were set to start recording; the room lighting was turned off, except the Philips Hue Go light and the lamp. The prototype 1 was projected on the screen with the audio playing from Brain.fm (Fig. 39). I informed the participant that I would ask him or her whether he or she wants to continue or stop the session, after 5-7 minutes. The session was observed from the back of the room. At the end, brain activity recording was stopped.

Figure 39. View during the session

7. The second part of the session started by asking the participant his or her preference on music genre from the preset. The lights were turned off the same way as the first part of the session. I informed participant that he or she can stop the session anytime or it can last until music track ends. The prototype 2 was projected on the screen with music playing from the selected genre.

8. The interview was conducted to inquire about participant's experience after the sessions were over. I asked several questions regarding his or her experience. The participant had freedom to talk about anything that came into his or her mind and elaborate on specific things. The following questions were asked:

- What was it like? Can you describe it?
- What you were thinking?
- How did you feel? Happy,sad,angry and etc.
- Did you have a feeling that your mind was connected or represented with the projected visual form?

- What do you think of the visual design/form?
- Did audio help or hinder? How?
- Did lighting help or hinder? How?
- What do you think, would be potential applications?

9. After the interview, I thanked the participant and asked him or her to fill out the short questionnaire (Fig. 40, 41).

Questionnaire for MFA thesis project

Bilegsaikhan Baasanjav
Visual Communication Design
School of Design
College of Imaging Arts and Sciences
Rochester Institute of Technology
April, 2016

1 Did you notice a change in your state of mind?
No, not at all ⟶ 1 2 3 4 5 ⟵ Yes, a lot

2 Do you feel less stressed?
No, not at all ⟶ 1 2 3 4 5 ⟵ Yes, a lot

3 Do you think project has potential use for meditation or therapy?
No, not at all ⟶ 1 2 3 4 5 ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 5 ⟵ Positive

6 What are three words that best describes your experience?

7 Any other thoughts?

Figure 40. The written questionnaire

Figure 41. The participant filling out a questionnaire

results and feedback

The evaluation results showed that the experience was both engaging and calming. Many of the participants mentioned that the mandala form was visually pleasing and effective to help them focus and meditate. They also indicated that the slow change in color and rotation speed was soothing and restful, which helped the overall experience.

Although the majority of participants liked the colors and time-based changes, some questioned the color associations and meanings of different levels. They inquired about visual changes and their associations to mental states, which to them, was not clear. In future revisions including the explanation of levels and color associations with different mental states will improve the installation.

qualitative method: interview

Observation, session recording and interviews were conducted with eight participants. The following questions were asked during the interview:

- What was it like? Can you describe it?
- What you were thinking?
- How did you feel? Happy, sad, angry and etc.
- Did you have a feeling that your mind was connected or represented with the projected visual form?
- What do you think of the visual design/form?
- Did audio help or hinder? How?
- Did lighting help or hinder? How?
- What do you think, would be potential applications?

The majority of participants expressed they had a positive overall experience, describing the first part of the session as calming, relaxing, meditative; and the second part as intriguing, interesting and immersive. Even though most of them tried to meditate or focus, some experimented to see how the visual form would react to different thoughts and emotions. Most of the participants liked prototype 1 (mandala form), commenting that the experience was very suitable and helpful for meditative purpose. However most of them didn't like the visual form from prototype 2, describing it as less interesting and a common visual pattern that is seen frequently.

There were some mixed opinions about whether they had a feeling of interaction with the visual form. Some participants strongly believed that their state of mind was clearly represented and interacted by the visual form; others didn't feel any notable connections to it.

All of the participants answered audio was essential for the experience. However most of them didn't notice the significance of the light. They thought light was redundant to the experience, suggesting to setup separately from the projection.

Finally, the question about potential applications, revealed many interesting suggestions, the following ideas are some of them:

- **Introductory meditation tool for non-practitioners.** This tool could support beginning meditation practitioners by providing visual feedback and tracking their progress. It could take a form of an application for watch, mobile, tablet, desktop or television.
- **Testing with different audiences.** Testing installation with different audiences like Deaf or hard of hearing people could reveal interesting results.
- **Virtual reality meditation application integrated with EEG headband.** Creating a virtual reality application connected with the EEG headband would enable users to meditate and relax anywhere without requiring a complex setup.
- **Tool for students to practice their concentration and focusing skills.** The tool would increase students' concentration skills. It would be especially useful for children with Attention Deficit Hyperactivity Disorder (ADHD). The summary of their brain activity could be shared with instructors so they can better instruct students.
- **Meditation tool for patients in the hospital.** The tool could be an aid for patients to overcome their pain and improve their mental state, so they can recover faster. It could be integrated into patients' room. The brain activity data could be shared with a doctor to analyze patient's mental state and provide necessary treatment.

qualitative method: questionnaire

In total, 41 people completed the questionnaire. Eight people participated in the full test session. The rest of the participants completed the form after participating in the short sessions during the public demonstration.

Questions and summary of answers:

1. Did you notice a change in your state of mind?
2. Do you feel less stressed?
3. Do you think project has potential use for meditation or therapy?
4. Do you think project has potential use for live performances?
5. How would you rank your overall experience?

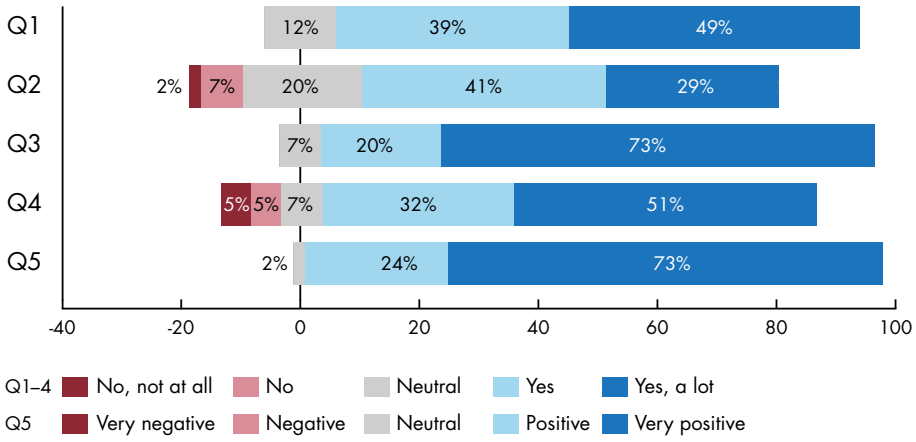

Figure 42. Summary of answers for questions 1 to 5

6. What are three words that best describes your experience?
   The following data visualization was generated using Voyant Tools–a web-based text analysis environment. The size of the font is based on the word's frequency (Fig. 43).

Figure 43. Summary of answers for question 6

7. Any other thoughts?
   The following are some of the answers.

- A very nice experience. Good choice of music :)
- Awesome work! Super interesting
- Very interesting approach, could be a great educational tool
- The colors worked very well. Great visualizations that drew me inside the centre
- I expect more visualization about live performance
- This reminded me of the old school animations you've would find on Winamp and Windows Media Player, which I think are no longer a thing :(
- The sensitivity if the image as it reacts to brain activity would make it more apparent thatmy brain was having a direct effect on the image
- Fantastic project!
- It was wonderful
- It was interesting to see my brain status. I think closing eyes helped meditation better because I felt easier to focus or clean my mind when closing my eyes

quantitative method

Eight people participated in the user testing. The brain activity recordings of two participants were unable to be retrieved due to the technical problems. The brain activity files recorded in MuseLab tool were converted to CSV files for the analysis. In order to make a correct comparison, session data recorded at the end was trimmed to match the time range of the before session recordings. Six participants' data were summarized and combined into the table (Table 5) (values are average of all scores detected):

Participant	**Delta**	**Theta**	**Alpha**	**Beta**	**Gamma**	***Conc.***	***Mellow***
P1 Before	**52.23**	**50.01**	**47.38**	45.15	**46.00**	**35.76**	**52.08**
P1 End	48.15	46.68	46.04	**45.66**	45.85	32.11	25.59
P2 Before	47.94	49.12	42.64	42.97	43.20	37.10	19.67
P2 End	**54.55**	**50.05**	**49.59**	**49.87**	**48.50**	**38.62**	**38.41**
P3 Before	**52.17**	**52.21**	**51.57**	**53.81**	46.32	47.75	**34.89**
P3 End	43.23	43.10	42.43	49.69	**50.04**	**54.39**	34.24
P4 Before	46.38	42.80	40.71	43.38	47.56	61.02	**30.11**
P4 End	**53.49**	**56.36**	**48.22**	**53.87**	**54.87**	**62.34**	23.56

P5 Before	**55.34**	**52.02**	45.43	**49.02**	43.93	38.83	24.18
P5 End	44.76	49.40	**50.42**	48.15	**46.87**	**49.55**	**48.07**
P6 Before	46.99	**56.97**	46.99	**50.72**	46.12	39.01	32.34
P6 End	**49.38**	51.26	**49.38**	49.61	**49.26**	**57.25**	**57.73**

Table 5. The summary of quantitative analysis

No notable patterns observed, except five out of six participants' concentration (experimental score) and gamma scores increased. It was evident that, to detect and confirm any notable patterns, testing with accurate scientific research methods and tools with bigger set of data is necessary. While the sample set was not enough to draw any scientific conclusions, this quantitative method could be used to evaluate and refine different visual forms in the future.

evaluation

dissemination

Project implementation was demonstrated at the following events:

- Imagine RIT - May 2016
- Thesis Show - May 2016

conclusion

conclusion

The evaluation results show that the project fulfilled the goal of creating visually engaging and meaningful experience, revealing variety of potential practical applications. Most of the participants who tested the interactive installation had a positive experience. They expressed the project has a great potential to be used for a meditation and relaxation purpose.

contribution to the discipline

The project contributes to the design discipline by bringing knowledge of psychology, Tibetan Buddhist philosophy and symbolism, to create meaningful content for an interactive experience. It could also lead to potential applications that contribute to the field of holistic medicine, by improving people's mental health and well-being.

personal reflection

The research on cognitive science and Buddhist philosophy broadened my understanding and enhanced my philosophical view; it sparked my personal interest even further.

The implementation of the project required me to learn the Processing language. This new programming language skill will surely help me with my future projects. These projects will be more focused on designing experiences that will be more intuitive and better integrated with our physical lives.

The project also showed me the importance of documentation and presentation of the research and the design process in written and verbal form.

limitations of the project

Credible and more substantial results could have been achieved by testing with wider range, and increased number of participants. Knowledge of data and signal analysis could have revealed more interesting interactions between the participant and the visual form.

directions for future research

Further research and development of three-dimensional representation of the abstract mandala could be used in the virtual reality applications. Also effects of the visual form, can be further studied with the help of experts in Buddhist philosophy and cognitive science.

appendixes

copy of signed thesis proposal

visualization of mind

visual exploration of brain activity
using neural interface

Thesis Proposal for
Master of Fine Arts Degree

Bilegsaikhan Baasanjav
Visual Communication Design
School of Design
College of Imaging Arts and Sciences
Rochester Institute of Technology

February 7, 2016

committee approval

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Daniel DeLuna, Associate Professor
Visual Communication Design, School of Design
College of Imaging Arts and Sciences

Signature of Chief Advisor | Date

Associate Advisor
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Signature of Associate Advisor | Date

contents

abstract

Since the ancient times philosophical and religious thinkers from West and East have made attempts to explain the nature of mind. It was nineteenth century when discoveries in psychology revealed that it is unconscious mind, subliminal world hidden deep within us, that governs our behavior. Today, modern technology enables scientists and scholars to see physical activity in the brain and allow them access deeper mental reality which has been unknown until now.

Project will explore methods in visualizing human brain activity or mental state using electroencephalogram neural interface to create visually engaging and meaningful user experience in the context of digital art.

Implementation of the project takes a form of a digital interactive art installation. It is a real-time visual representation of the human brain activity using electroencephalogram (EEG) neural interface. Interface transmits brain wave signal stream of the user's brain activity to the computer where it is analyzed and used as an input parameter to the program. Program generates visual form and outputs it to the projection system where user can observe it.

In order to create appropriate visual concept, research has been done in areas of psychology and visual design.

Installation is evaluated based on users' experience that is analyzed using video-cued recall method, a combination of observation, data recording and interview. Project is an experimental interactive digital art, however it may reveal other potential applications.

keywords

visualization of mind, digital art, eeg visual, installation art, cognitive psychology, unconscious mind, processing, brain computer interface, mental wellness, mind and cognition, buddhism, mandala

introduction

introduction

What is mind? Since ancient times thinkers and philosophers have been trying to answer this question. There are variety of different explanations from many distinctive point of views. Yet it still remains one of the most fascinating and unexplored subjects of human nature.

Consciousness and unconsciousness have been distinguished since the Greek times. However among the most influential thinkers who were investigating psychology of consciousness was the eighteenth-century philosopher Immanuel Kant. His theory speculated that we constantly build a picture of our surroundings rather than merely documenting events, and human perceptions are not based what exists but rather somehow created—and constrained—by the mind. During his time, psychology was not an independent subject but merely an all-around category. Despite it, his theory was very near to modern views. It was nineteenth-century when physiologist E. H. Weber conducted simple experiment that lead to new stage of psychology where one can discover mathematical and scientific laws through experimentation. Subsequently many scientists like Wilhelm Wundt, William Carpenter, Charles Peirce and William James delved into the subject and uncovered facts about unconscious mind. Thanks to their study, we know our unconscious mind has knowledge unknown to the conscious mind, and massive amount of information we perceive is processed outside of our awareness therefore dictating our behavior.

As a person who has an interest in cognitive psychology and philosophy, I asked myself following:

- Can we visually represent our conscious and unconscious mind?
- What kind of visual form would it take?
- Can we interact with our mind?

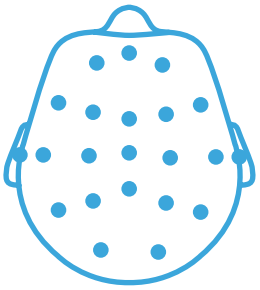
This project is the attempt to answer these questions by exploring and creating meaningful and visually engaging user experience.

situation analysis

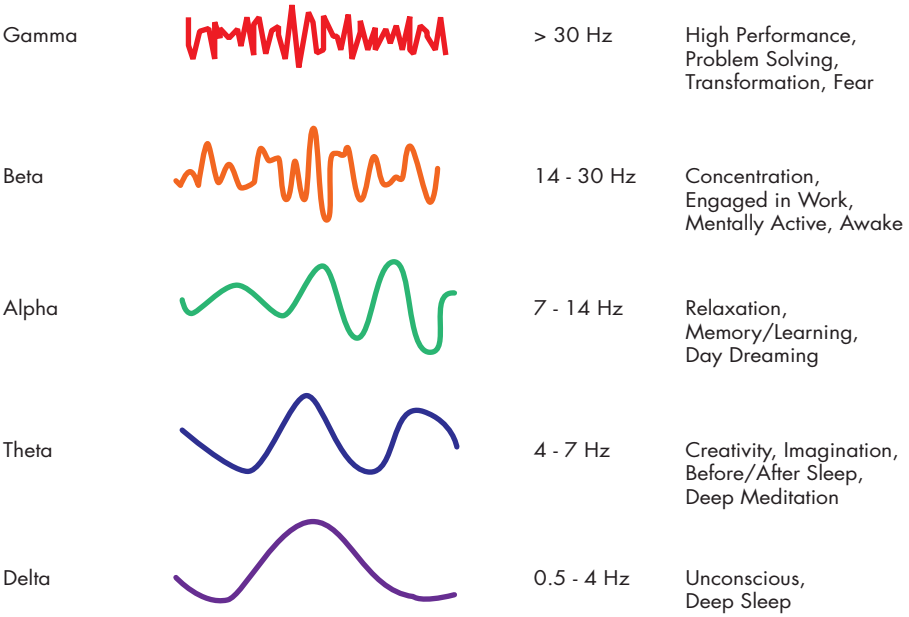
There are number of brain imaging methods that allow physicians and scientists to observe human brain activities. *Functional magnetic resonance imaging* (fMRI), emerged in 1990s, revolutionized science of cognitive psychology. It produces three-dimensional images showing which parts of the brain are involved during particular mental task. It works by mapping activity of the brain by detecting blood oxygenation and flow that occur in response to neural activity.

There are other methods like *Computed Tomography* (CT), *Positron Emission Tomography* (PET), *Electroencephalography* (EEG) and etc. Among them, EEG is one of the earliest and most affordable method of monitoring brain activity. It monitors electrical activity of the brain by attaching electrodes along the scalp. It continues to be popular tool for researchers because of its ability to track activities on a millisecond-level which is not possible with MRI and CT scans.

EEG records brain wave signals that have different frequency bands; they are named *alpha* (8–13 Hz) *delta* (1–4 Hz), *theta* (4–8 Hz), *beta* (13–30 Hz) and *gamma* (30–70 Hz). Each frequency band relates to different mental states, for example increase in the alpha waves can be detected when the person is in the state of relaxed wakefulness when eyes are closed; it decreases when eyes are open. However these interpretations are general assumptions and cannot be stated as a direct association with mental state.



***Electroencephalography (EEG)** is an electrophysiological monitoring method to record electrical activity of the brain*



Brain wave signals associated to different mental states

applications

Traditionally EEG has been used as a medical tool to diagnose brain disorders, and the research grade EEG equipment has costed several thousands of dollars. Today, continuous decrease in cost of digital devices makes EEG devices more affordable and accessible. Over recent years, several consumer and research level EEG *brain computer interface* (BCI) devices have been released. These devices allowed research community to build and experiment projects of wide range of non-medical purposes that wasn't achievable before.

- Assistive Technology
- Communication
- Game and Entertainment
- Neuromarketing and advertisement
- Mental Health

Assistive Technology
One of the first non-medical applications was creating assistive devices for people with paralysis like Amyotrophic Lateral Sclerosis (ALS) disease. In 2009, Toyota and research foundation RIKEN built a wheelchair for people with paralysis or severe disabilities. It has a skull cap EEG sensor and a display that assists with control; it could successfully respond to the drivers intention or brain wave signals to complete commands like turning left, right and stop. It proved to be successful and had potential to be further used as an interface for prosthetic and human enhancement devices.

Communication
In 2014, International team of researchers and engineers published paper describing first successful attempt of brain-to-brain communication. They successfully transmitted words 'hola' and 'ciao' across internet between two human subjects using EEG and robot-assisted and image-guided transcranial magnetic stimulation (TNS). Although it is far from being practical, it might be the first step of the future communication technology.

Game and Entertainment
One of the most successful or promising EEG application is considered to be game industry. Neurosky was one of the pioneer companies that introduced EEG controllers into the market with headset called MindWave, device aimed at gaming and simple video applications. Researchers think EEG games might be a possible solution to help people, especially children, with attention problems learn to focus better.

Neuromarketing and Advertisement
Neuromarketing is a relatively new field of marketing research that instead of conventional methods of consumer testing studies consumers' cognitive response to marketing stimuli. Researchers and companies that use neuromarketing believe traditional methods produce inaccurate results because participants can never express their unconscious feeling. Therefore using EEG, fMRI scans help them find out how people really feel at their subconscious level when they make decisions about the product or service.

Mental Health
Mental health is critical aspect these days, with faster internet connection and more advanced mobile devices, we are being bombarded with enormous amount of information, thus creating information fatigue–a stress disorder. In order to help people to maintain their mental well-being, EEG devices are being used as a biometric tool that monitors and analyzes one's emotional or cognitive state. For instance, commercially developed Muse EEG headset device comes with a mobile application that helps a person to meditate by showing how calm or relaxed the person is.

thesis statement

Project will explore methods in visualizing human brain activity or mental state using electroencephalogram neural interface to create visually engaging and meaningful user experience in the context of digital art.

research

review of literature

psychology

Subliminal: How Your Unconscious Mind Rules Your Behavior
Leonard Mlodinow
Vintage Books
2013

This book explains how surprising our subliminal mind works, and how actively it influences our conscious experience of the world. It begins explaining how our unconscious mind works by referring to important scholars' work and experiments in the history of cognitive psychology. It also describes how our minds misperceive our relationships with family, friends; and how we misremember important events in our lives, changing our memories along the way. For me it was a good introduction to the subject, well written, entertaining and easy to understand.

Man and His Symbols
Carl Gustav Jung, Marie-Luise von Franz
Dell Pub.
1968

Influential Swiss psychologist and physician Carl Gustav Jung's last work where he explains the importance of symbolism, particularly as revealed in dreams. He emphasizes the significance of knowledge of unconscious–a knowledge communicated through dreams and symbols. Illustrations and figures are valuable reference to develop a visual concept.

The Red Book: Liber Novus
Carl Gustav Jung, Sonu Shamdasani
W.W. Norton & Co
2009

Manuscript crafted by Carl Gustav Jung between 1915 and about 1930. He was self experimenting by voluntary confronting with the unconscious through willful engagement of what Jung later termed "mythopoetic imagination". He documented his experience in small journals from where he transcribed notes into manuscript. Book contains illustrations created to represent his visual

experience. Illustrations were main object of study and important reference that will help form a visual concept.

Mandala symbolism
Carl Gustav Jung
Princeton University Press
1972

Author makes deep analyzes on illustrations drawn by his patients, comparing them to mandala, symbol which appears in philosophical and religious texts throughout the history especially in Hindu and Tibetan Buddhism. Most of the drawings had close resemblance to mandalas, even though patients didn't have any prior knowledge about it. He hypothesized that it is a visual message transmitted by an unconscious mind to represent its state or convey a message. Analysis of mandala illustrations accompanied with their interpretations were very valuable to decide a visual concept.

The Mandala: sacred circle in Tibetan Buddhism
Martin Brauen
Shambala Publications
1998

This book is a translation of the Martin Brauen's original book in German published in 1992. Martin Brauen shares us with his detailed study of the meaning, function and rituals related to Kalacakra mandala. It contains beautiful illustrations, photos, and diagrams that extremely helpful for readers to understand meaning and structure of mandala forms. Last chapter of the book discusses about notion of western philosophy and science on mandala symbols. It specifically mentions Carl Jung's view on collective unconsciousness, archetype and symbolism, and how it relates to mandala.

design

Generative art: a practical guide using processing
Matt Pearson
Manning
2011

Book starts with the brief discussion of history of algorithmic and generative art. Then it presents many code examples that create from simple line to fractals. Examples were clearly divided into steps with explanations.

Envisioning information
Edward Rolf Tufte
Graphics Press
2008

Author presents a collection of some the best examples of information design,

contrasting with some of the worst ones. Then he diligently points out concept and principles that make the great examples–great.

Interaction of Color
Josef Albers
Yale University Press
2013

Author explains the principles of color theory in simple and efficient manner. He explains people's perception of color and how it can be changed through creating an interaction between multiple colors. Book consists of exercises that help readers to reinforce what they learned from each section.

technical

Learning Processing: a beginner's guide to programming images, animation, and interaction
Daniel Shiffman
Morgan Kaufmann/Elsevier
2008

In addition to being a solid introductory book of programming in processing language, it shows references of information, techniques, and extra libraries and other topics to continue develop projects beyond the scope the text.

oscP5
Andreas Schlegel
2011
http://www.sojamo.de/libraries/oscP5/
Accessed Feb 12, 2016

oscP5 is an implementation of the Open Sound Control protocol for processing environment. Website contains instructions, examples and class reference document. oscP5 library is used to transmit brain wave signals from EEG neural interface to processing environment.

others

Interactive experience in the digital age: evaluating new art practice
Linda Candy, Sam Ferguson
Springer
2014

Book explores development of interactive digital art and discusses difference and problems of using formal Human Computer Interaction (HCI) evaluation methods and suggest new methods of evaluating digital art based on practitioners feedback. Book is a necessary reference to form a evaluation strategy to evaluate this project.

Sense and sensibility: evaluation and interactive art
Kristina Höök, Phoebe Sengers, Gerd Andersson
ACM Press
2003

This paper describes two-tiered evaluation method authors developed in order to evaluate interactive art piece. Paper complains traditional HCI evaluation methods are not suitable for evaluating interactive art. Paper provides with valuable case study.

ideation

concept

Concept is to create a real-time interactive experience where one can observe a visual representation of their brain activity or mental state, and perhaps consciously manipulate visual output. The visual form will take form of an abstract mandala.

Analysis will be used to determine possible applications for this methodology. However it has high potential to be used as a meditation, therapy tool or real-time generative audio-visual projection for live performances. User experience will be documented through observations and follow-up interviews.

methodology

The project arouse from idea of combining practice of digital art with emerging biometric wearable device technology. Combining them opens new possibilities in visual communication field, creating vast potential for experimentation.

Unlike science methodology, which after establishing the truth, or design methodology, which tries to solve a problem, art methodology is about making the most effective form through which ideas, feeling, perceptions can be communicated to a user, making it suitable methodology for this project. In addition, project is experimental in nature, it embraces chaos, unpredictability and abandonment of processes free of control. There isn't right or wrong way, artwork is an expression of humanity coming from the deepest level of the mind. Outcome might be indefinable, however it is critical to evaluate outcome through observation and survey of user experience.

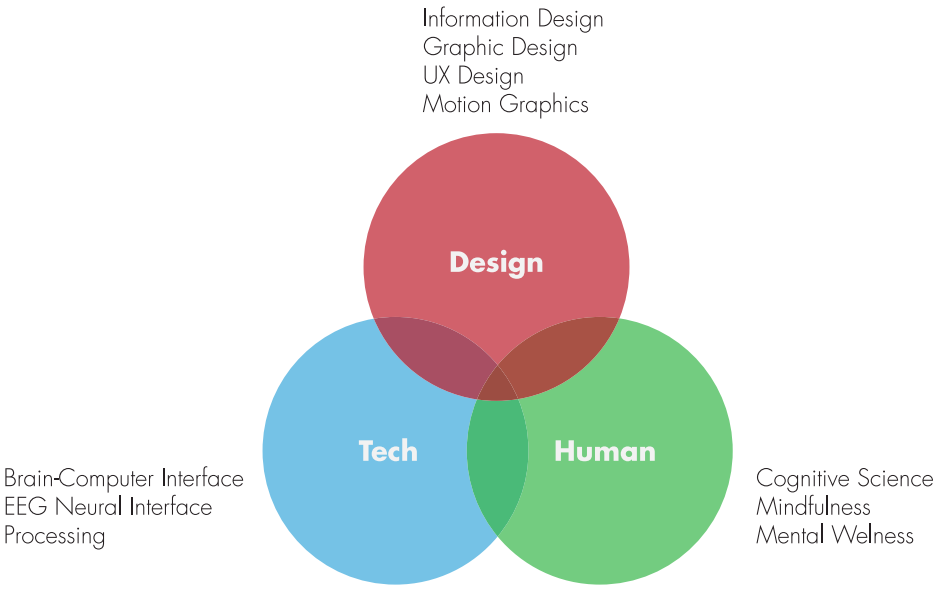
areas of interest

Project is the integration of research and study of following main components.

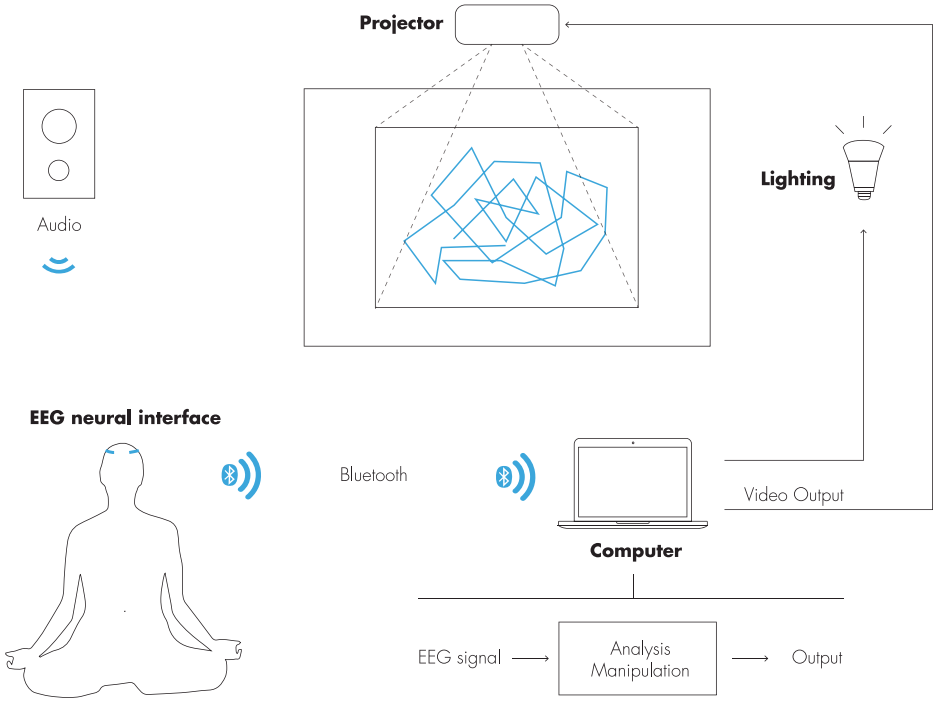
Human
Study of psychology is essential not only to understand how our mind works, but also to essential to develop meaningful use

Design
Subjects like information design, motion graphics, generative art and algorithmic art are essential to devise an engaging visual look.

Technology
Knowledge of programming and computer tools is necessary to realize implementation of the project



installation idea



Participant will wear EEG neural interface and will start short session of audio visual meditation. Participant will experience aesthetic visual output of their brain activity while listening meditative music.

Setup consists of EEG neural interface which sends brain wave stream data, and a computer that receives and analyzes brain wave stream data to

manipulate variables of the visual form. EEG interface transmits brain wave signal stream via Bluetooth connection. Computer will receive input signal stream, and processes them as an input parameter to the program which manipulates visual output and lighting of the room.

Session will be observed and recorded to evaluate possibility of using setup as a potential meditation, psychotherapy tool. In addition, potential of using the installation as an audio video projection setup for live performances will be evaluated through participants' survey .

visual concept

Significant amount of time and energy spent on doing research, which was essential in order to determine meaningful and compelling rationale behind the visual concept.

Initial research led me to influential work of Carl Gustav Jung in psychiatry and psychology. He believed at the basis of separate individual consciousness and the unconsciousness, there is the collective unconscious, the common heritage of all humanity and the universal source of all conscious life. He also believed the unconscious is psychic reality which has own language that is used to communicate with consciousness, a language of images and symbols. He refers to those as archetypes, the most ancient and universal thought-form of human beings.

It was during years of self-experimentation, when he experimented with unconsciousness, that he started sketching a mandala. The book "The Red Book: Liber Novus"[1], a collection of diaries he made during his self-experimentation with unconsciousness, contains astonishing illustrations that are clearly resemble mandala symbols.

What is mandala? It is a mystic circle form, very important and significant in Tantric Buddhism. It is one of the most ancient symbols, which according to Jung can be traced to Paleolithic time and can be found in all places and all ages in history. He also assumes that mandala is an archetype of order, of wholeness, a natural attempt of self-healing. It is considered as a representation of the universe and an aid to meditation.

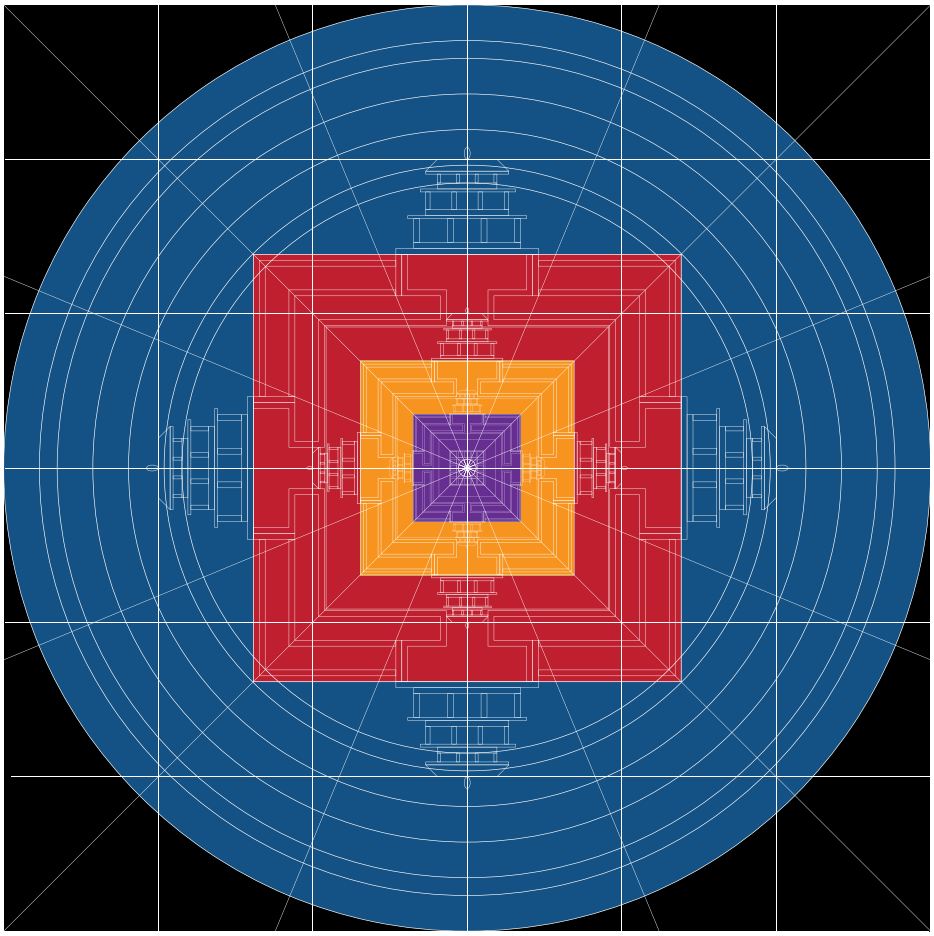
I selected Mandala is the most favorable visual form that can visually represent human mind and its nature. Visual form of this project will consist of the abstract mandala form, which will be designed based on fundamental

1 C. G. Jung, Sonu Shamdasani, and C. G. Jung. The Red Book: Liber Novus. 1st ed. The Red Book: Liber Novus vols. Philemon Series. New York: W.W. Norton & Co, 2009.

structure and attributes of the traditional Kalacakra mandala[2]. The principle of polarity, fundamental in both Jung's model and Buddhism philosophy, will be taken into consideration during the design process.

mandala

Tantric Buddhism is the most visually intensive Buddhist practice in the Buddhism. It is widely known for its extensive repertoire of symbols, deities and mandalas. Visualization or pictorial representations serve as an aid to the meditator. Kalacakra mandala is produced during Kalacakra ritual, and being considered as one of the most complex forms in Buddhism. Structurally it consists of outer and inner parts. Outer part consists of components of the five discs, symbolically representing universe or outer cosmos, namely: space, air, water, fire and earth. Inner part which has close correlations with human body, symbolically considered to be a person. It consists of body, speech and mind components which structurally correspond to human anatomy.



2 Martin Brauen. The Mandala: Sacred Circle in Tibetan Buddhism. Boston; [New York]: Shambhala ; Distributed in the U.S. by Random House, 1998.

Structure of Kalacakra mandala. Built on 6 by 6 grid, each grid is subdivided into 26 units. Colors represent scope of each level: Purple–mind leve, orange–speech level, red–body level, blue-outer cosmos.

audio

Music will be played from the Brain.fm service, an algorithmically generated engine designed to create background music for studying, sleeping, or relaxation.

color

Colors mainly will be referenced from Tibetan mandalas, it will be also chosen for its psychological and therapeutic effect.

Lower signal values will shift the appearance of colors toward an adjacent deeper hue. Higher signal values will shift them toward lighter hues.

lighting

Lighting of the room will be changed according to brain wave signals, color and warmth of it will be selected on its psychological and therapeutic effect.

time-based

Visual elements will change its *scale*, *rotation*, *color* and other visual parameters throughout the session according to each brain wave frequency band values. Each bands' signal value will be used as an input, based on which visual parameters will be manipulated on their respective level.

Frequency Bands	Level	Mandala Level
Delta	1-4Hz	Mind
Theta	5-8Hz	Mind and Speech
Alpha	9-13Hz	Speech
Beta	12-30Hz	Speech and Body
Gamma	30-50Hz	Body

In addition to frequency bands, data ouput from accelerometer will be input parameter on Mandala's Body level.

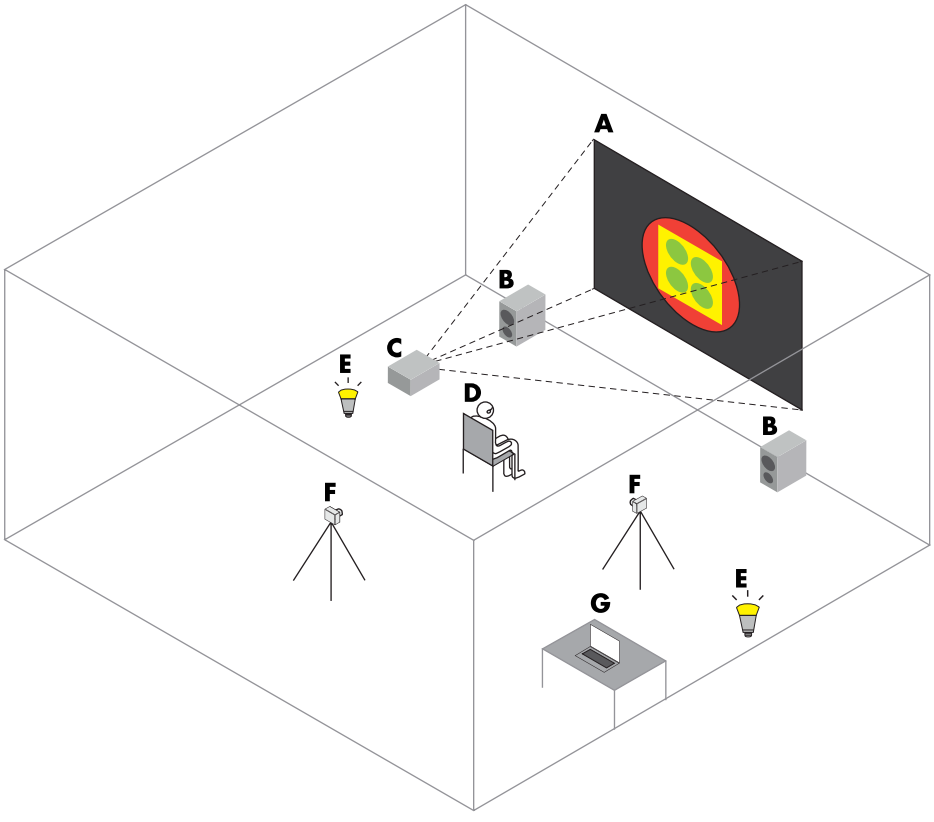
implementation

implementation

Project implementation will take form of an interactive installation art.

setup

Installation will be setup in the spacious dark room with stereo speakers, computer, projector, screen, digital cameras and lights. Participant will wear EEG interface and sit on the chair located in the middle of the room. Participant will observe visual output projected on the screen while listening to the music played.



Prospective setup of the installation. A: screen, B: stereo speaker, C: projector, D: user wearing EEG interface sitting on the chair, E: wirelessly connected lights, F: digital cameras for video recording, G: Computer and a table

tools

Project implementation requires both hardware and software tools, they are listed below:

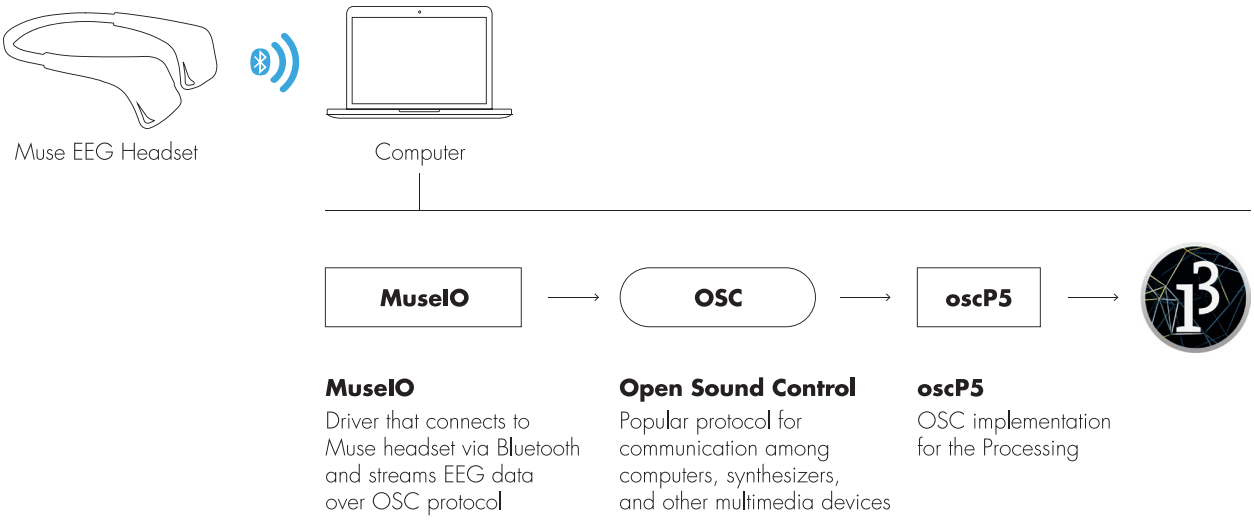
Hardware

- Muse EEG headset
- Wireless Light (2)
- Stereo speaker
- Digital cameras (2)
- Computer
- Projector
- Screen

Software

- MuseIO
- Processing
- oscP5 library for Processing
- controlP5 library for Processing

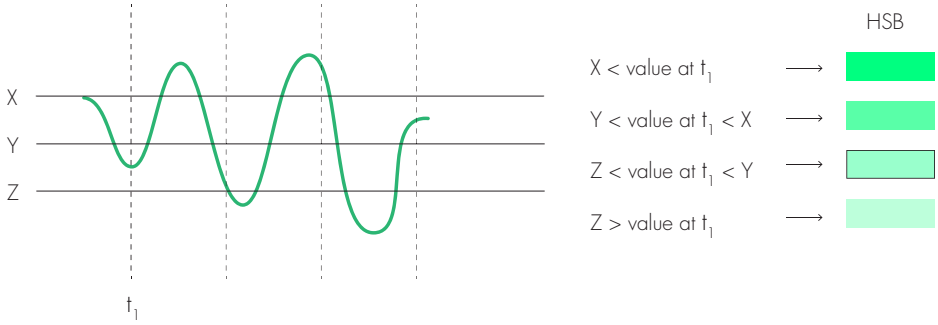
Following diagram shows general setup of connection between devices. EEG brain wave signal stream will be transmitted from headset over OSC protocol via Bluetooth using MuseIO driver. In the Processing environment EEG signal stream will be received using oscP5 library and will be available as a numerical data stream.



Software components required to send brain wave signal stream into Processing

Once signal stream will be available in the Processing environment, it will be analyzed and passed as an input parameter to the program every preset time interval, manipulating visual output and lighting of the room.

Program will check brain wave data stream value at every preset time interval. Depending on those values, visual and motion parameters will be altered.



example of color manipulation according to the signal value at the time point t_1

connecting devices

Following is the step by step process of connecting and setting up Muse EEG neural interface to send datastream using OSC protocol via Bluetooth and receive it in Processing environment.

- Pairing Muse EEG headset with computer via Bluetooth connection.
- Data stream is served on UDP protocol on port 5000.
  `muse-io --device DeviceName --osc osc.udp://localhost:5000`
- Receiving data stream using oscP5 library for Processing. It listens to server created in the previous step using UDP protocol on port 5000.
  `oscP5client = new OscP5(this, 5000, OscP5.UDP);`

EEG data

Muse EEG neural tracks brain activity through seven sensors – two on the forehead, two behind ears, three forehead reference sensors. Its MuseIO SDK gives access to rich data including raw EEG data and computed data that are filtered and computed from raw EEG values. Computed data is run through a series of computations to make data easier to use without complexity of understanding signal processing, neuroscience or machine learning. These computed data can be accessed through Muse Elements[1]. It can be described as an algorithm and signal processing pack. SDK also provide with configuration presets[2] that can change device's settings and configurations based on specific needs. For this project, preset 14 was chosen, because it provides accelerometer data, compression, error data and other relevant features.

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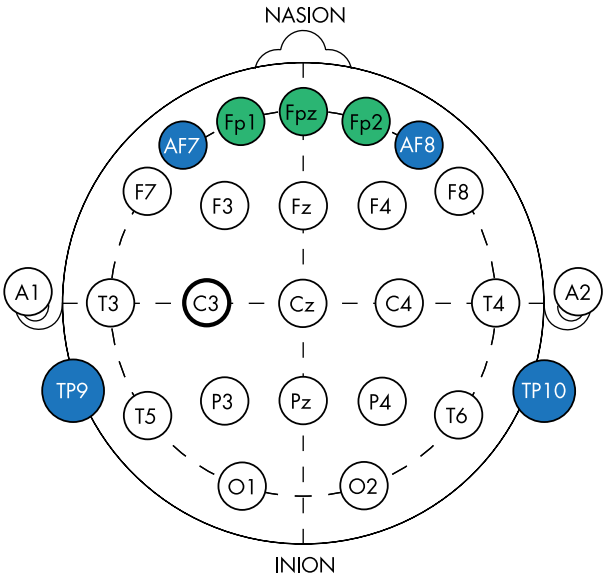
1 "Available Data." Muse Developers. Accessed March 9, 2016. http://developer.choosemuse.com/research-tools/available-data.

2 "Headband Configuration Presets." Muse Developers. Accessed March 9, 2016. http://developer.choosemuse.com/hardware-firmware/headband-configuration-presets.



Muse EEG headset sensor locations shown on the International 10–20 system for EEG electrode placement. At preset 14, device will detect brain activity on TP9, Fp1, Fp2, TP10.

Muse Element provides several different types of values computed from the raw EEG data. Because of the ease of use "Band Power Session Scores" data type will be used. It gives values between 0 and 1 by comparing the user's current band power value to an average of their recent historical values. Following table shows detailed specifications:

MuseIO Paths	/muse/elements/delta_session_score /muse/elements/theta_session_score /muse/elements/alpha_session_score /muse/elements/beta_session_score /muse/elements/gamma_session_score	
Units	Unitless	
Datatype	floats	
Transmission frequency	10 Hz	
OSC Data Format	Four channels for each band power: ffff	
Frequency Ranges	**Name**	**Frequency Range**
	Delta Session Score	1-4Hz
	Theta Session Score	5-8Hz
	Alpha Session Score	9-13Hz
	Beta Session Score	12-30Hz
	Gamma Session Score	30-50Hz

prototype

First simple prototype has been developed to show concept and process. It is a processing sketch that draws vertical lines every 1/6 of a second. Each vertical line has a color which hue and brightness value is determined according to alpha wave signal value received from the EEG interface. Presuming alpha waves values change according to user's state of focus, program visually represents user's focused state with darker lines, and unfocused state with red.

Visual output from the prototype

deliverables

Final deliverables for this project are:

- **Interactive installation**
  It will be setup for public dissemination during Imagine RIT 2016.
- **Visual**
  Unique mandala form will be designed exclusively for the installation.
  It will be submitted as a vector illustration and motion graphic video.
- **Photo and video footage**
  All recorded photos and video footages will be submitted as an archive material.
- **Evaluation documents**
  Project will be evaluated with minimum of six people. All user sessions video, interviews and survey will be submitted.
- **Source codes**
  All programming source codes developed for this project will be submitted and released publicly under a Creative Commons license.

evaluation

evaluation plan

Interactive installation shares many common qualities with traditional artwork; both have physical construction and create experiences to the audience. Generally artwork communicates its artistic message, however it can be of experimental nature as well. Interactive installation differs from traditional artwork by encouraging users to become a part of the artwork by interacting with it.

Traditional Human Computer Interaction evaluation methods measure usability of the software or digital system. However they often fail when it comes to evaluation of the interactive digital installations. Therefore more appropriate evaluation method is needed, because main concern of the project is users' experience when interacting with the artwork.

After some research on evaluation methods used on similar interactive projects, video-cued recall method has been chosen as most optimal method of evaluating this project. It consists of:

- Observation - observation while recording
- Data recording - video recording of the session
- Interview - questions will be asked while participant is watching a video
- Questionnaire - optional one page written questionnaire

Its purpose is to observe participant's experience during interactive session. Observation will be documented by video recording which will be played afterwards to help facilitate interview by helping participant to recall his or her experience. Coordinator will conduct an interview by asking questions about user's experience followed by written questionnaire.

evaluation

dissemination

Project will be disseminated at following events and online resources:

- Imagine RIT - May 2016
- Thesis Show - May 2016

timeline

february

Feb	15	Receive EEG neural interface
Feb	17	Prototype development
Feb	24	Software setup and testing
Feb	25	Committee meeting

march

Mar	2	First prototype testing
Mar	2	Develop initial Processing sketches
Mar	11	Second prototype (refined)
Mar	18	Second prototype test
Mar	25	Committee meeting
Mar	31	Vector visuals

april

Apr	4	Motion prototype
Apr	8	Processing prototype test
Apr	15	Evaluation
Apr	19	Evaluation and feedback
Apr	22	Submit first draft of written thesis document
Apr	25	Committee meeting

may

May	2	Submit written thesis document
May	6	Thesis defense
May	7	Imagine RIT
May	13	Thesis show

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source codes

Source codes for the Prototype 1

Filename: Prototype.pde

```
import java.util.Map;
import oscP5.*;

PShape mandala, lotus, fader;
int flag=1, prevFlag;
color tempC;

OscP5 oscP5; // Muse OSC listener
int recvPort = 6000;
String localhost = "127.0.0.1";
int[] oscVal = {0,0,0};

PhilipsHue light = new PhilipsHue(this, "1"); //Philips Hue Controller Light 1

// Note the HashMap's "key" is a String and "value" is an MandalaElement
HashMap<String, MandalaElement> mandalaLayer = new HashMap<String, MandalaElement>();
ArrayList<MandalaElement> lotusLayer = new ArrayList<MandalaElement>();

// Brainwave Frequency Band
int[] gammaOsc = new int[4];
int[] betaOsc = new int[4];
int[] alphaOsc = new int[4];
int[] thetaOsc = new int[4];
int[] deltaOsc = new int[4];
float gammaOscAvg;
float betaOscAvg;
float alphaOscAvg;
float thetaOscAvg;
float deltaOscAvg;
float totalAvg;

// Global Parameters
int startTimeFader=0;
int startTimeA=0;
int startTimeB=0;
int startTimeC=0;
int frameR= 24;
int alpha = 100;
```

```
int margin = 100; // margin from bottom and top of the screen
int transitTime = 2000; // transition time between styles
int oscRetrieveDelay = 500; // amount of interval between reading OSC
float alphaVel = (alpha/((transitTime/1000*frameR)/5));
float aAccelRange = 0.002;

float strokeCol = 254;
int strokeChange = -1;

void setup() {
  fullScreen(1);
  //size(800, 600);
  frameRate(frameR);
  smooth(2);
  background(0);
  hint(ENABLE_STROKE_PURE);

  colorMode(HSB, 360, 100, 100, 100); // Setting color mode to HSB 360,100,100

  oscP5 = new OscP5(this, localhost, recvPort, OscP5.UDP);

  // Transition fader
  fader = createShape(RECT, 0, 0, width, height);
  fader.setFill(0);
  fader.setStroke(false);

  /*************** Style A initialization ***************/
  // The SVG file must be in the data folder
  // of the current sketch to load successfully
  mandala = loadShape("Mandala_Stroke.svg");

  mandalaLayer.put("wisdom", new MandalaElement(mandala.getChild("wisdom"), false));
  mandalaLayer.put("space", new MandalaElement(mandala.getChild("space"), false));
  mandalaLayer.put("small_circles_air", new MandalaElement(mandala.getChild("small_circles_air"), false));
  mandalaLayer.put("small_circles_fire", new MandalaElement(mandala.getChild("small_circles_fire"), false));
  duplicateElem(mandalaLayer, "circle_", 6, 0, color(355, 72, 64));
  mandalaLayer.put("air", new MandalaElement(mandala.getChild("air"), false));
  mandalaLayer.put("fire", new MandalaElement(mandala.getChild("fire"), false));
  mandalaLayer.put("water", new MandalaElement(mandala.getChild("water"), false));
  mandalaLayer.put("earth", new MandalaElement(mandala.getChild("earth"), false));
  mandalaLayer.put("sunmoon", new MandalaElement(mandala.getChild("sunmoon"), false));
  duplicateElem(mandalaLayer, "body_out_", 4, aAccelRange, color(7,78,81));
  duplicateElem(mandalaLayer, "body_in_", 4, aAccelRange, color(7,78,81));
  duplicateElem(mandalaLayer, "speech_out_", 4, aAccelRange, color(207,100,68));
  duplicateElem(mandalaLayer, "speech_in_", 4, aAccelRange, color(207,100,68));
  duplicateElem(mandalaLayer, "mind_out_", 4, aAccelRange, color(135,48,60));
  duplicateElem(mandalaLayer, "mind_in_", 4, aAccelRange, color(135,48,60));
  mandalaLayer.put("lotus", new MandalaElement(mandala.getChild("lotus"), true));
  duplicateElem(mandalaLayer, "depth_c", 4, 0, color(295, 36, 49));

  // Initial Parameter Setup
  /*
  Angular/Rotational Speed Table
```

```
0.005 > x        - Very Slow
0.005 < s < 0.01  - Slow
0.010 < s < 0.02  - Medium
0.020 < s < 0.30  - Hight
*/
mandalaLayer.get("wisdom").fillColor = color(295, 36, 49);
mandalaLayer.get("space").fillColor = color(218, 19, 33);
mandalaLayer.get("air").fillColor = color(199, 23, 86);
mandalaLayer.get("fire").fillColor = color(355, 72, 64);
mandalaLayer.get("water").fillColor = color(196, 100, 67);
mandalaLayer.get("earth").fillColor = color(145, 100, 58);
mandalaLayer.get("small_circles_fire").fillColor = color(355, 72, 64);
mandalaLayer.get("small_circles_air").fillColor = color(199, 23, 86);
mandalaLayer.get("sunmoon").fillColor = color(145, 100, 58);
mandalaLayer.get("sunmoon").aVelocity = 0.003;
mandalaLayer.get("small_circles_fire").aVelocity = -0.002;
mandalaLayer.get("small_circles_air").aVelocity = 0.002;
mandalaLayer.get("lotus").aVelocity = 0.03;
mandalaLayer.get("lotus").min_aVelocity = 0.002;

MandalaElement objTemp;
float temp;
for(int x=0; x < 4; x++){
   temp=0.0001 + x/500.0;
   objTemp = mandalaLayer.get("body_out_"+str(x));
   objTemp.min_aVelocity += random(temp);
   objTemp.max_aVelocity += random(temp);
   objTemp.min_sat = 10;
   objTemp.min_bri = 10;

   objTemp = mandalaLayer.get("body_in_"+str(x));
   objTemp.min_aVelocity += random(temp);
   objTemp.max_aVelocity += random(temp);
   objTemp.min_sat = 10;
   objTemp.min_bri = 10;

   objTemp = mandalaLayer.get("speech_out_"+str(x));
   objTemp.min_aVelocity += random(temp);
   objTemp.max_aVelocity += random(temp);
   objTemp.min_sat = 10;
   objTemp.min_bri = 10;

   objTemp = mandalaLayer.get("speech_in_"+str(x));
   objTemp.min_aVelocity += random(temp);
   objTemp.max_aVelocity += random(temp);
   objTemp.min_sat = 10;
   objTemp.min_bri = 10;

   objTemp = mandalaLayer.get("mind_out_"+str(x));
   objTemp.min_aVelocity += random(temp);
   objTemp.max_aVelocity += random(temp);
   objTemp.min_sat = 10;
   objTemp.min_bri = 10;
```

```
    objTemp = mandalaLayer.get("mind_in_"+str(x));
    objTemp.min_aVelocity += random(temp);
    objTemp.max_aVelocity += random(temp);
    objTemp.min_sat = 10;
    objTemp.min_bri = 10;
  }

   for(int x=0; x < 6; x++){
    temp=0.001 + x/1000;
    objTemp = mandalaLayer.get("circle_"+str(x));
    objTemp.aVelocity =  random(temp);
    objTemp.max_aVelocity = 0.005;
  }

  //noLoop();
}

void keyPressed() {
  if (key == '1' && flag != 1){
    prevFlag=flag;
    flag=1;
    startTimeFader = millis();
    alpha = 0;
  } else if(key == '2' && flag != 2){
    prevFlag=flag;
    flag=2;
    startTimeFader = millis();
    alpha = 0;
  } else if(key == '3' && flag != 3){
    prevFlag=flag;
    flag=3;
    startTimeFader = millis();
    alpha = 0;
  } else if(key == 's'){
    saveFrame("screen-####.png");
  }
}

void draw(){
  updateOSC();
  updatePhilipsHue();
  transitionCheck();
}

void styleB(){
  background(0);
}

void styleA(){
  background(0);
  // Check Brainwave Data
  // Update every 2 seconds
```

```
if(startTimeA==0 || timer(startTimeA, oscRetrieveDelay)==0){
 // Body Outer
 float shift,shiftSatBri;

 for(int x=0; x < 4; x++){
    mandalaLayer.get("depth_c"+str(x)).scale_accel = random(-deltaOscAvg/100000,0);
 }

 mandalaLayer.get("sunmoon").aAcceleration = aVelShiftVal(int(gammaOscAvg));
 mandalaLayer.get("small_circles_fire").aAcceleration = aVelShiftVal(int(alphaOscAvg));
 mandalaLayer.get("small_circles_air").aAcceleration = aVelShiftVal(int(thetaOscAvg));
 mandalaLayer.get("lotus").aAcceleration = aVelShiftVal(int(deltaOscAvg));

 shiftSatBri = satBriShiftVal((gammaOscAvg+betaOscAvg+alphaOscAvg)/3);
 for(int x=0; x < 6; x++){
  mandalaLayer.get("circle_"+str(x)).aAcceleration = aVelShiftVal(int(alphaOscAvg));
  mandalaLayer.get("circle_"+str(x)).shiftFillColor(0,shiftSatBri,shiftSatBri);
 }
 mandalaLayer.get("earth").shiftFillColor(0,shiftSatBri,shiftSatBri);
 mandalaLayer.get("sunmoon").shiftFillColor(0,shiftSatBri,shiftSatBri);
 //shiftSatBri = satBriShiftVal(betaOscAvg);
 mandalaLayer.get("water").shiftFillColor(0,shiftSatBri,shiftSatBri);
 //shiftSatBri = satBriShiftVal(alphaOscAvg);
 mandalaLayer.get("fire").shiftFillColor(0,shiftSatBri,shiftSatBri);
 mandalaLayer.get("small_circles_fire").shiftFillColor(0,shiftSatBri,shiftSatBri);
 //shiftSatBri = satBriShiftVal(thetaOscAvg);
 mandalaLayer.get("air").shiftFillColor(0,shiftSatBri,shiftSatBri);
 mandalaLayer.get("small_circles_air").shiftFillColor(0,shiftSatBri,shiftSatBri);
 //shiftSatBri = satBriShiftVal(deltaOscAvg);
 mandalaLayer.get("space").shiftFillColor(0,shiftSatBri,shiftSatBri);
 //shiftSatBri = satBriShiftVal(deltaOscAvg);
 mandalaLayer.get("wisdom").shiftFillColor(0,shiftSatBri,shiftSatBri);

 for(int x=0; x < 4; x++){

  // Rotation Speed Update
  mandalaLayer.get("body_out_"+str(x)).aAcceleration = aVelShiftVal(gammaOsc[x]);
  mandalaLayer.get("body_in_"+str(x)).aAcceleration = aVelShiftVal(betaOsc[x]);
  mandalaLayer.get("speech_in_"+str(x)).aAcceleration = aVelShiftVal(alphaOsc[x]);
  mandalaLayer.get("speech_out_"+str(x)).aAcceleration = aVelShiftVal(thetaOsc[x]);
  mandalaLayer.get("mind_in_"+str(x)).aAcceleration = aVelShiftVal(deltaOsc[x]);
  mandalaLayer.get("mind_out_"+str(x)).aAcceleration = aVelShiftVal(deltaOsc[x]);

  // Color Update
  shift = colorShiftVal(gammaOscAvg);
  shiftSatBri = satBriShiftVal(gammaOscAvg);
  mandalaLayer.get("body_out_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);

  shift = colorShiftVal(betaOscAvg);
  shiftSatBri = satBriShiftVal(betaOscAvg);
  mandalaLayer.get("body_in_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);

  shift = colorShiftVal(alphaOscAvg);
```

```
    shiftSatBri = satBriShiftVal(alphaOscAvg);
    mandalaLayer.get("speech_out_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);

    shift = colorShiftVal(thetaOscAvg);
    shiftSatBri = satBriShiftVal(thetaOscAvg);
    mandalaLayer.get("speech_in_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);

    shift = colorShiftVal(deltaOscAvg);
    shiftSatBri = satBriShiftVal(deltaOscAvg);
    mandalaLayer.get("mind_in_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);
    mandalaLayer.get("mind_out_"+str(x)).shiftFillColor(shift,shiftSatBri,shiftSatBri);
    shiftSatBri = satBriShiftVal((gammaOscAvg+betaOscAvg+alphaOscAvg)/3);
    mandalaLayer.get("depth_c"+str(x)).shiftFillColor(0,shiftSatBri,shiftSatBri);
   }

   startTimeA = millis(); //restart timer
  }

  //Animate Depth Circles;
  MandalaElement objTemp;
  for(int x=0; x < 4; x++){
    objTemp = mandalaLayer.get("depth_c"+str(x));
    if(objTemp.scale <= 0.93){
     objTemp.scale = 1;
     objTemp.shape.resetMatrix();
    }
  }

  for (Map.Entry elem : mandalaLayer.entrySet()) {
   if(elem != null){
    objTemp = (MandalaElement)elem.getValue();
    objTemp.update();
   }
  }

  mandalaLayer.get("water").update();
  mandalaLayer.get("air").update();

}

void duplicateElem(HashMap hm, String key, int times, float aAccelRange, color c){
  String newKey;
  MandalaElement objTemp;
  for(int x=0; x < times; x++){
    newKey = key+str(x);
    objTemp = new MandalaElement(mandala.getChild(newKey), false);
    objTemp.fillColor = c;
    hm.put(newKey, objTemp);
    objTemp.aVelocity = random(aAccelRange);
  }
}

int timer(int start, int duration) {
```

```
  int remainingTime = (start+duration)-millis();

  if(remainingTime > 0){
    return remainingTime;
  }else {
    remainingTime = 0;
    return remainingTime;
  }
}

void transitionCheck(){
  int remainingTime = timer(startTimeFader, transitTime);
  if(remainingTime > 0){
    if(remainingTime > transitTime/2){
      alpha += alphaVel;
      styleSwitcher(prevFlag);
    }else{
      alpha -= alphaVel;
      styleSwitcher(flag);
    }
    alpha = constrain(alpha,0,100);
    fader.setFill(color(2, alpha));
    shape(fader,0,0);
  }else{
    styleSwitcher(flag);
  }
}

void styleSwitcher(int flag){
  if(flag==1)
     styleB();
  else if(flag==2)
     styleA();
}

void updateOSC(){

  println("Delta:"+deltaOsc[0]+","+deltaOsc[1]+","+deltaOsc[2]+","+deltaOsc[3]);
  println("Theta:"+thetaOsc[0]+","+thetaOsc[1]+","+thetaOsc[2]+","+thetaOsc[3]);
  println("Alpha:"+alphaOsc[0]+","+alphaOsc[1]+","+alphaOsc[2]+","+alphaOsc[3]);
  println("Beta:"+betaOsc[0]+","+betaOsc[1]+","+betaOsc[2]+","+betaOsc[3]);
  println("Gamma:"+gammaOsc[0]+","+gammaOsc[1]+","+gammaOsc[2]+","+gammaOsc[3]);

  deltaOscAvg = arrayAverage(deltaOsc);
  thetaOscAvg = arrayAverage(thetaOsc);
  alphaOscAvg = arrayAverage(alphaOsc);
  betaOscAvg = arrayAverage(betaOsc);
  gammaOscAvg = arrayAverage(gammaOsc);
  totalAvg = (gammaOscAvg+betaOscAvg+alphaOscAvg+thetaOscAvg+deltaOscAvg)/5;

  println("Delta Avg:"+deltaOscAvg);
  println("Theta Avg:"+thetaOscAvg);
  println("Alpha Avg:"+alphaOscAvg);
```

```
  println("Beta Avg:"+betaOscAvg);
  println("Gamma Avg:"+gammaOscAvg);
  println("Total Avg:"+totalAvg);
}

void oscEvent(OscMessage msg) {
  if(msg.checkAddrPattern("/muse/elements/delta_session_score")==true){
    deltaOsc[0] = int(msg.get(0).floatValue()*100);
    deltaOsc[1] = int(msg.get(1).floatValue()*100);
    deltaOsc[2] = int(msg.get(2).floatValue()*100);
    deltaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/theta_session_score")==true){
    thetaOsc[0] = int(msg.get(0).floatValue()*100);
    thetaOsc[1] = int(msg.get(1).floatValue()*100);
    thetaOsc[2] = int(msg.get(2).floatValue()*100);
    thetaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if (msg.checkAddrPattern("/muse/elements/alpha_session_score")==true) {
    alphaOsc[0] = int(msg.get(0).floatValue()*100);
    alphaOsc[1] = int(msg.get(1).floatValue()*100);
    alphaOsc[2] = int(msg.get(2).floatValue()*100);
    alphaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/beta_session_score")==true){
    betaOsc[0] = int(msg.get(0).floatValue()*100);
    betaOsc[1] = int(msg.get(1).floatValue()*100);
    betaOsc[2] = int(msg.get(2).floatValue()*100);
    betaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/gamma_session_score")==true){
    gammaOsc[0] = int(msg.get(0).floatValue()*100);
    gammaOsc[1] = int(msg.get(1).floatValue()*100);
    gammaOsc[2] = int(msg.get(2).floatValue()*100);
    gammaOsc[3] = int(msg.get(3).floatValue()*100);
  }
}

void updatePhilipsHue(){
  light.Hue = int(map(totalAvg, 20, 80, 0, 62225));
  light.Saturation = int(map(totalAvg, 0, 100, 127, 255));
  light.Brightness = int(map(totalAvg, 0, 100, 10, 80));
  light.updateColor();
}

float arrayAverage(int arr[]) {
  float sum = 0;
  for (float f: arr)  sum += f;
  return sum/arr.length;
}

int colorShiftVal (float score){
      int ret=0;
      if(score > 80 && score < 100) ret=7;
      else if(score > 60 && score <= 80) ret=5;
      else if(score > 50 && score <= 60) ret=3;
      else if(score > 40 && score <= 50) ret=-3;
```

```
    else if(score > 20 && score <= 40) ret=-5;
    else if(score <= 20) ret=-7;
    return ret;
}
int satBriShiftVal (float score){
    int ret=0;
    if(score > 80 && score < 100) ret=6;
    else if(score > 60 && score <= 80) ret=5;
    else if(score > 50 && score <= 60) ret=3;
    else if(score > 45 && score <= 50) ret=2;
    else if(score > 40 && score <= 45) ret=1;
    else if(score > 30 && score <= 40) ret=-1;
    else if(score > 20 && score <= 30) ret=-2;
    else if(score <= 20) ret=-5;
    return ret;
}

float aVelShiftVal (int score){
    float ret=0;
    if(score > 80 && score < 100) ret=0.0005;
    else if(score > 60 && score <= 80) ret=0.0003;
    else if(score > 50 && score <= 60) ret=0.0002;
    else if(score > 40 && score <= 50) ret=-0.0001;
    else if(score > 20 && score <= 40) ret=-0.0002;
    else if(score <= 20) ret=-0.0003;
    return ret;
}
```

Filename: MandalaElement.pde

```
class MandalaElement {
  float pos_x, pos_y;
  float scale_x, scale_y;
  boolean enableStyle = true;
  boolean noStroke = true;
  PShape shape;
  float aVelocity = 0.0;  // Angular Velocity
  float aAcceleration = 0; // Angular Acceleration
  color fillColor = color(0,0,0);
  color strokeColor = color(0,0,0);
  int strokeWeight = 2;
  float scale = 1;
  float scale_accel = 0;
  float max_aVelocity = 0.015;
  float min_aVelocity = 0.002;
  float min_sat = 10;
  float max_sat = 90;
  float min_bri = 10;
  float max_bri = 100;
  int colorVelocity = 1;

  MandalaElement(PShape pshape, boolean styleFlg){
    pos_x = 0;
    pos_y = 0;
    if(pshape !=null){
      shape = pshape;
      if(!styleFlg){
        enableStyle=false;
        shape.disableStyle();
      }
    }
    setPosition(width/2,height/2);
  }

  void setPosition(float xpos, float ypos) {
    pos_x = xpos;
    pos_y = ypos;
  }

  void setFillColor(color tempColor){
    fillColor = color(tempColor);
  }

  void setStrokeColor(color tempColor){
    strokeColor = color(tempColor);
  }

  void shiftFillColor(float gapHue, float gapSat, float gapBri) {
    float tempHue, tempSat, tempBri;
    tempHue = hue(fillColor) + gapHue;
    tempSat = saturation(fillColor) + gapSat;
```

```
  tempBri = brightness(fillColor) + gapBri;

  tempHue=constrain(tempHue,0,360);
  tempSat=constrain(tempSat,min_sat,max_sat);
  tempBri=constrain(tempBri,min_sat,max_bri);
  fillColor = color(round(tempHue), round(tempSat), round(tempBri));
 }

 void updateScale() {
  if(shape != null){
   scale += scale_accel;
   //scale = constrain(aVelocity, -0, max_aVelocity);
   shape.scale(scale);
  }
 }

 void updateRotation() {
  if(shape != null){
   aVelocity += aAcceleration;
   aVelocity = constrain(aVelocity, min_aVelocity, max_aVelocity);
   shape.rotate(aVelocity);
  }
 }

 void update() {
  if(shape !=null) {
   fill(fillColor);
   if(!noStroke){
    stroke(strokeColor);
    strokeWeight(strokeWeight);
   }else{
    noStroke();
   }
   shape(shape, pos_x, pos_y, height-margin, height-margin);
   updateRotation();
   updateScale();
  }
 }
}
```

Filename: PhilipsHue.pde

```
import processing.net.*;

class PhilipsHue{

  String apiKey = "DtIWYclOcmsQ95EGc8T7-C6o-elamLhoQ2zEbNEG"; //developer name used when setting up
bridge
  String light = ""; //the light # you want to control
  String ipaddress = "129.21.169.70";
  int port = 80;

  int prev = 0;
  int prev1 = 0;
  int prev2 = 0;

  int Brightness = 127;
  int Saturation = 127;
  int Hue = 127;

  Client c;
  String data;
  processing.core.PApplet parent;

  PhilipsHue(processing.core.PApplet parentRef, String lightNo){
    parent = parentRef;
    light = lightNo;
  }

  void updateColor(){
     update("{\"hue\":" + Hue +",\"sat\":" + Saturation +",\"bri\":" + Brightness+"}");
  }

  void update(String json){
     c = new Client(parent, ipaddress, port); // Connect to server on port 80
     c.write("PUT /api/" + apiKey +"/lights/" + light + "/state HTTP/1.1\r\n");
     c.write("Content-Length: " + (18 + json.length()) + "\r\n\r\n");
     c.write(json+"\r\n");
     c.write("\r\n");
     c.stop();
     //sendHTTPData();

     //println("sent:");  // command executed
     delay(1); // slight delay
  }

  void sendHTTPData() {
     if (c.available() > 0) { // If there's incoming data from the client...
       data = c.readString(); // ...then grab it and print it
       //println(data);
     }
  }
}
```

Source codes for the Prototype 2

Filename: Prototype2.pde

```
import java.util.Map;
import oscP5.*;

PShape mandala, lotus, fader;
int flag=1, prevFlag;
color tempC;

OscP5 oscP5; // Muse OSC listener
int recvPort = 5000;
String localhost = "127.0.0.1";
int[] oscVal = {0,0,0};

PhilipsHue light = new PhilipsHue(this, "1"); //Philips Hue Controller Light 1

ArrayList<GenElement> genLayer = new ArrayList<GenElement>();

// Brainwave Frequency Band
int[] gammaOsc = new int[4];
int[] betaOsc = new int[4];
int[] alphaOsc = new int[4];
int[] thetaOsc = new int[4];
int[] deltaOsc = new int[4];
float gammaOscAvg;
float betaOscAvg;
float alphaOscAvg;
float thetaOscAvg;
float deltaOscAvg;
float totalAvg;

// Global Parameters
int startTimeFader=0;
int startTimeA=0;
int startTimeB=0;
int startTimeC=0;
int frameR= 24;
int alpha = 100;
int margin = 100; // margin from bottom and top of the screen
int transitTime = 2000; // transition time between styles
int oscRetrieveDelay = 500; // amount of interval between reading OSC
float alphaVel = (alpha/((transitTime/1000*frameR)/5));
float aAccelRange = 0.002;

float strokeCol = 254;
int strokeChange = -1;

void setup() {
  fullScreen();
  //size(800, 600);
  frameRate(frameR);
```

```
  smooth();
  background(0);
  blendMode(SCREEN);

  colorMode(HSB, 360, 100, 100, 100); // Setting color mode to HSB 360,100,100

  oscP5 = new OscP5(this, localhost, recvPort, OscP5.UDP);

  // Transition fader
  fader = createShape(RECT, 0, 0, width, height);
  fader.setFill(0);
  fader.setStroke(false);

  //noLoop();
}

void keyPressed() {
  if (key == '1' && flag != 1){
    prevFlag=flag;
    flag=1;
    startTimeFader = millis();
    alpha = 0;
  } else if(key == '2' && flag != 2){
    prevFlag=flag;
    flag=2;
    startTimeFader = millis();
    alpha = 0;
  } else if(key == 's'){
    saveFrame("screen-####.png");
  }
}

void draw(){
  updateOSC();
  //updatePhilipsHue();
  transitionCheck();
}
void styleB(){
  background(0);
}

void styleA(){
  background(0);

  float prevAngle=0;
  if(genLayer.size()>0)
    prevAngle = genLayer.get(genLayer.size()-1).angle;
  else
    prevAngle = -PI/2;

  GenElement tempObj = new GenElement(prevAngle);
  tempObj.strokeHue = map(totalAvg,10,70,320,0);
```

```
  tempObj.strokeSat = map(totalAvg,10,70,40,100);
  tempObj.strokeBri = map(totalAvg,10,70,40,100);
  tempObj.opacity = map(totalAvg,10,70,30,60);
  tempObj.angnoise += totalAvg/10.0;
  tempObj.radiusnoise += totalAvg/10.0;
  tempObj.xnoise += totalAvg/100.0;
  tempObj.ynoise += totalAvg/100.0;
  //tempObj.shiftStrokeColor(colorShiftVal(totalAvg),satBriShiftVal(totalAvg),satBriShiftVal(totalAvg));
  genLayer.add(tempObj);
  if(genLayer.size() > 200)
    genLayer.remove(0);

  for (GenElement elem : genLayer) {
    if(elem != null){
      elem.draw();
    }
  }
}

int timer(int start, int duration) {
  int remainingTime = (start+duration)-millis();

  if(remainingTime > 0){
    return remainingTime;
  }else {
    remainingTime = 0;
    return remainingTime;
  }
}

void transitionCheck(){
  int remainingTime = timer(startTimeFader, transitTime);
  if(remainingTime > 0){
    if(remainingTime > transitTime/2){
      alpha += alphaVel;
      styleSwitcher(prevFlag);
    }else{
      alpha -= alphaVel;
      styleSwitcher(flag);
    }
    alpha = constrain(alpha,0,100);
    fader.setFill(color(2, alpha));
    shape(fader,0,0);
  }else{
    styleSwitcher(flag);
  }
}

void styleSwitcher(int flag){
  if(flag==1)
     styleB();
  else if(flag==2)
```

```
    styleA();
}

void updateOSC(){

  println("Delta:"+deltaOsc[0]+","+deltaOsc[1]+","+deltaOsc[2]+","+deltaOsc[3]);
  println("Theta:"+thetaOsc[0]+","+thetaOsc[1]+","+thetaOsc[2]+","+thetaOsc[3]);
  println("Alpha:"+alphaOsc[0]+","+alphaOsc[1]+","+alphaOsc[2]+","+alphaOsc[3]);
  println("Beta:"+betaOsc[0]+","+betaOsc[1]+","+betaOsc[2]+","+betaOsc[3]);
  println("Gamma:"+gammaOsc[0]+","+gammaOsc[1]+","+gammaOsc[2]+","+gammaOsc[3]);

  deltaOscAvg = arrayAverage(deltaOsc);
  thetaOscAvg = arrayAverage(thetaOsc);
  alphaOscAvg = arrayAverage(alphaOsc);
  betaOscAvg = arrayAverage(betaOsc);
  gammaOscAvg = arrayAverage(gammaOsc);
  totalAvg = (gammaOscAvg+betaOscAvg+alphaOscAvg+thetaOscAvg+deltaOscAvg)/5;

  println("Delta Avg:"+deltaOscAvg);
  println("Theta Avg:"+thetaOscAvg);
  println("Alpha Avg:"+alphaOscAvg);
  println("Beta Avg:"+betaOscAvg);
  println("Gamma Avg:"+gammaOscAvg);
  println("Total Avg:"+totalAvg);
}

void oscEvent(OscMessage msg) {
  if(msg.checkAddrPattern("/muse/elements/delta_session_score")==true){
    deltaOsc[0] = int(msg.get(0).floatValue()*100);
    deltaOsc[1] = int(msg.get(1).floatValue()*100);
    deltaOsc[2] = int(msg.get(2).floatValue()*100);
    deltaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/theta_session_score")==true){
    thetaOsc[0] = int(msg.get(0).floatValue()*100);
    thetaOsc[1] = int(msg.get(1).floatValue()*100);
    thetaOsc[2] = int(msg.get(2).floatValue()*100);
    thetaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if (msg.checkAddrPattern("/muse/elements/alpha_session_score")==true) {
    alphaOsc[0] = int(msg.get(0).floatValue()*100);
    alphaOsc[1] = int(msg.get(1).floatValue()*100);
    alphaOsc[2] = int(msg.get(2).floatValue()*100);
    alphaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/beta_session_score")==true){
    betaOsc[0] = int(msg.get(0).floatValue()*100);
    betaOsc[1] = int(msg.get(1).floatValue()*100);
    betaOsc[2] = int(msg.get(2).floatValue()*100);
    betaOsc[3] = int(msg.get(3).floatValue()*100);
  } else if(msg.checkAddrPattern("/muse/elements/gamma_session_score")==true){
    gammaOsc[0] = int(msg.get(0).floatValue()*100);
    gammaOsc[1] = int(msg.get(1).floatValue()*100);
    gammaOsc[2] = int(msg.get(2).floatValue()*100);
    gammaOsc[3] = int(msg.get(3).floatValue()*100);
```

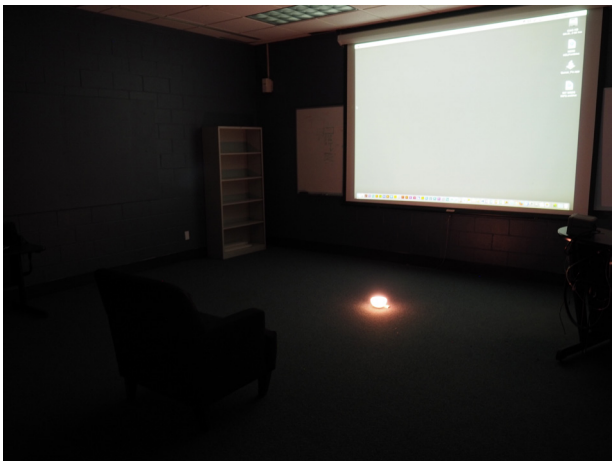
```
  }
}

void updatePhilipsHue(){
  light.Hue = int(map(totalAvg, 20, 80, 0, 62225));
  light.Saturation = int(map(totalAvg, 0, 100, 127, 255));
  light.Brightness = int(map(totalAvg, 0, 100, 10, 80));
  light.updateColor();
}

float arrayAverage(int arr[]) {
  float sum = 0;
  for (float f: arr)  sum += f;
  return sum/arr.length;
}

int colorShiftVal (float score){
    int ret=0;
    if(score > 80 && score < 100) ret=7;
    else if(score > 60 && score <= 80) ret=5;
    else if(score > 50 && score <= 60) ret=3;
    else if(score > 40 && score <= 50) ret=-3;
    else if(score > 20 && score <= 40) ret=-5;
    else if(score <= 20) ret=-7;
    return ret;
}
int satBriShiftVal (float score){
    int ret=0;
    if(score > 80 && score < 100) ret=6;
    else if(score > 60 && score <= 80) ret=5;
    else if(score > 50 && score <= 60) ret=2;
    else if(score > 40 && score <= 50) ret=1;
    else if(score > 20 && score <= 40) ret=-2;
    else if(score <= 20) ret=-5;
    return ret;
}

float aVelShiftVal (int score){
    float ret=0;
    if(score > 80 && score < 100) ret=0.0005;
    else if(score > 60 && score <= 80) ret=0.0003;
    else if(score > 50 && score <= 60) ret=0.0002;
    else if(score > 40 && score <= 50) ret=-0.0001;
    else if(score > 20 && score <= 40) ret=-0.0002;
    else if(score <= 20) ret=-0.0003;
    return ret;
}
```

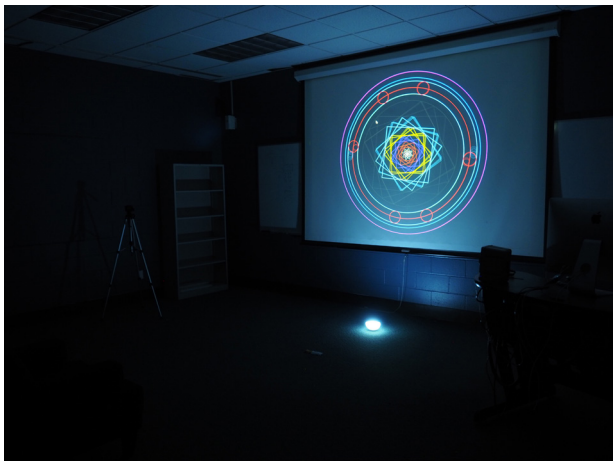
Filename: GenElement.pde

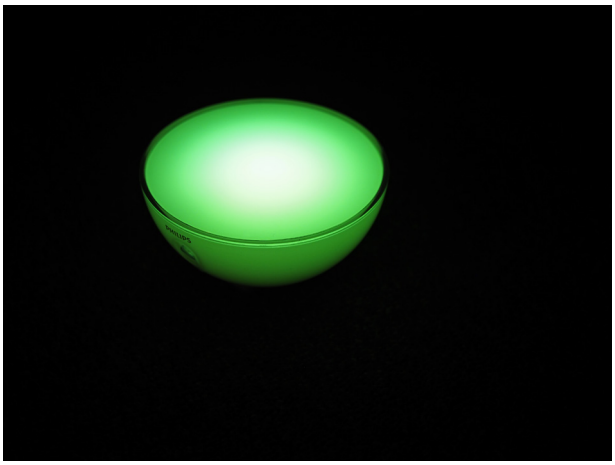
```
class GenElement {
 float angnoise=0, radiusnoise=0;
 float angle = -PI/2;
 float radius = height/2-margin;
 float strokeHue = 0;
 float strokeSat = 0;
 float strokeBri = 0;
 int strokeChange = -1;
 float  xnoise = 0.02;
 float  ynoise = 0.02;
 float opacity = 100;

 GenElement(float prevAngle){
  angnoise += 0.005;
  angle = prevAngle + (noise(angnoise) * 6)-3;
 }

 void draw(){
  angnoise += 0.005;
  angle += (noise(angnoise))/50;

  //radiusnoise += 0.001;
  radius = (noise(radiusnoise)*550);

  float centreX = width/2 + (noise(xnoise) * 200) - 100;
  float centreY = height/2 + (noise(ynoise) * 200) - 100;

  float rad = radians(angle);
  float x1 = centreX + (radius * cos(rad));
  float y1 = centreY + (radius * sin(rad));

  // opposite
  float opprad = rad + PI;
  float x2 = centreX + (radius * cos(opprad));
  float y2 = centreY + (radius * sin(opprad));
  noFill();
  //strokeCol=constrain(strokeCol,0,360);
  stroke(strokeHue,strokeSat,strokeBri,int(opacity));
  strokeWeight(1);
  line(x1, y1, x2, y2);
 }
}
```

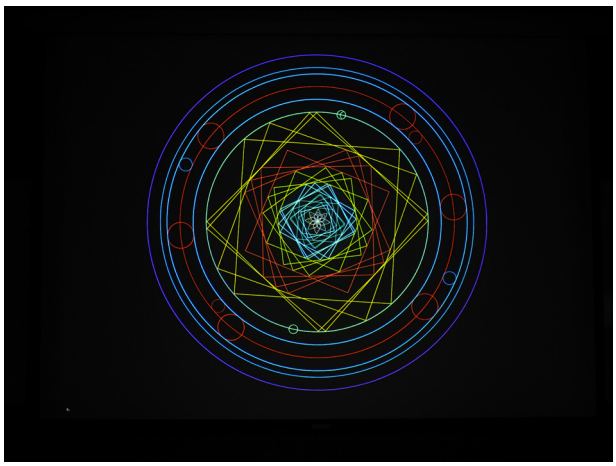
PhilipsHue.pde is the same file used with Prototype 1.

installation photos

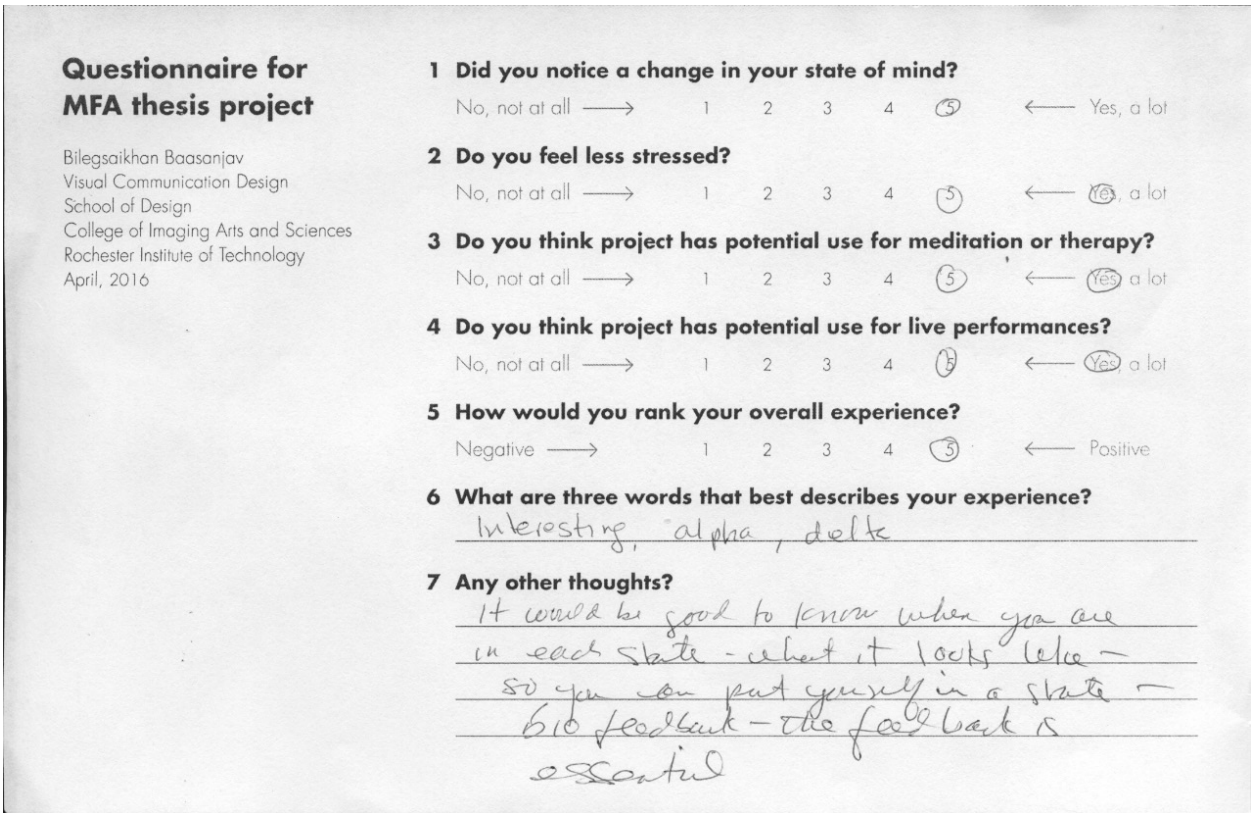








questionnaires



Questionnaire for MFA thesis project

Bilegsaikhan Baasanjav
Visual Communication Design
School of Design
College of Imaging Arts and Sciences
Rochester Institute of Technology
April, 2016

1 Did you notice a change in your state of mind?

No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

2 Do you feel less stressed?

No, not at all ⟶ 1 2 3 4 (5) ⟵ (Yes), a lot

3 Do you think project has potential use for meditation or therapy?

No, not at all ⟶ 1 2 3 4 (5) ⟵ (Yes) a lot

4 Do you think project has potential use for live performances?

No, not at all ⟶ 1 2 3 4 (5) ⟵ (Yes) a lot

5 How would you rank your overall experience?

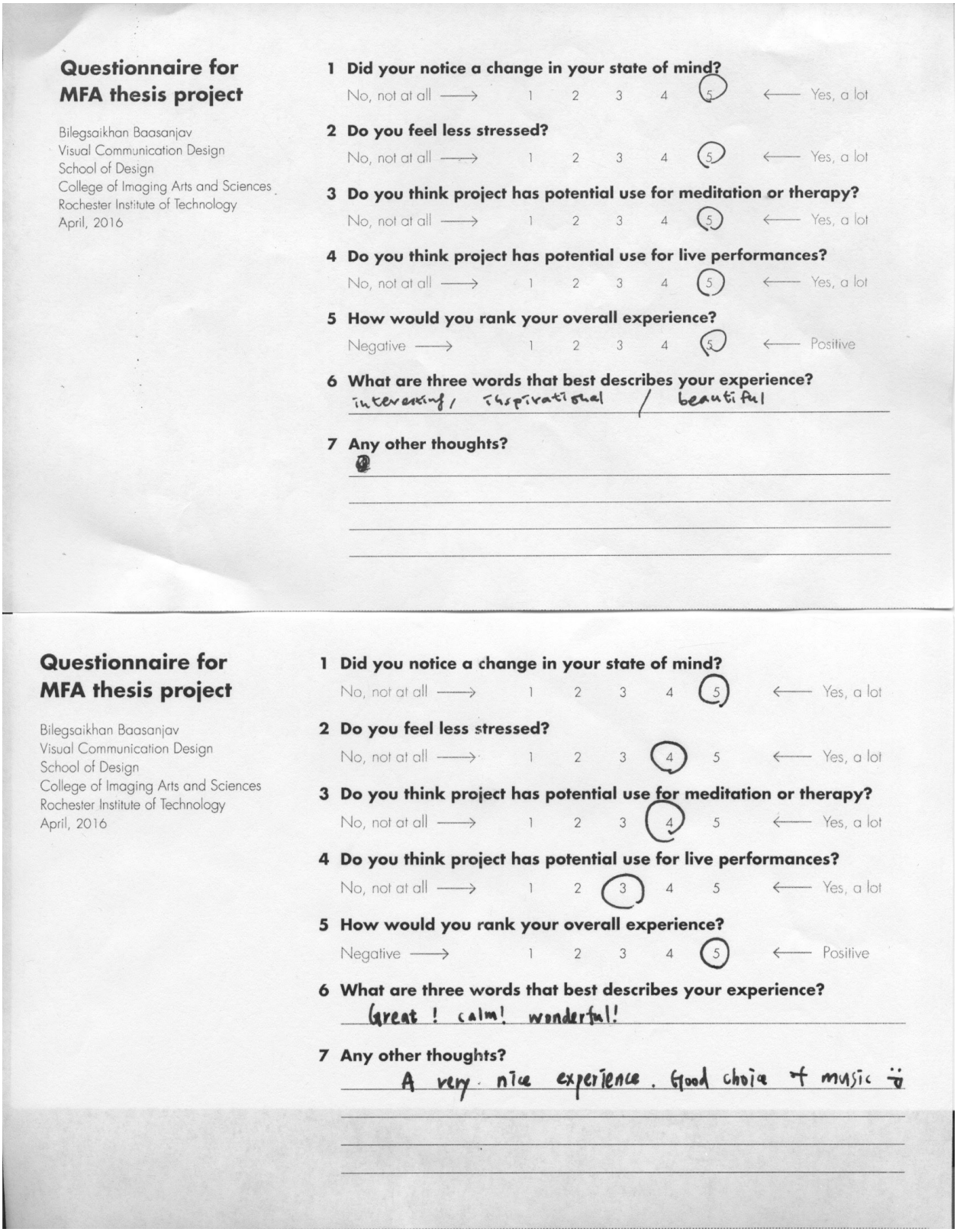
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?

Interesting, alpha, delta

7 Any other thoughts?

It would be good to know when you are in each state - what it looks like - so you can put yourself in a state - bio feedback - the feedback is essential



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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
interesting / Inspirational / beautiful

7 Any other thoughts?
@

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1 Did you notice a change in your state of mind?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

2 Do you feel less stressed?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

3 Do you think project has potential use for meditation or therapy?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 (3) 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Great ! calm! wonderful!

7 Any other thoughts?
A very nice experience. Good choice of music :o

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 (3) 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
Relaxing, intriguing, wild

7 Any other thoughts?
Very interesting approach, could be a great educational tool.

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Mesmerizing Intense Captivating

7 Any other thoughts?
The colors worked very well. Great visualizations that drew me in right at the centre.

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No, not at all ⟶ 1 2 (3) 4 5 ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
peaceful, calm. curious.

7 Any other thoughts?
I expect more visualization about live performance.

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4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
enticing immersive colorful

7 Any other thoughts?
This reminded me of the old school animations you would find on Winamp and Windows Media Player, which I think are no longer a thing.!!

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4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
INTERESTING, CALMING, CENTERING.

7 Any other thoughts?
FANTASTIC PROJECT!

Questionnaire for MFA thesis project

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
calming, sensory, meditative

7 Any other thoughts?
The sensitivity of the image as it reacts to brain activity would make it more apparent that my brain was having a direct effect on the image.

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4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 (3) 4 5 ⟵ Positive

6 What are three words that best describes your experience?
focused. appreciation. calm. peaceful. clean.

7 Any other thoughts?
It was interesting to see my brain status. I think closing eyes helps meditation a lot better because I felt easier to focus or clean my mind when closing my eyes.

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4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Thought Provoking and relaxing

7 Any other thoughts?
its was wonderful

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
cool relaxing fun

7 Any other thoughts?

Questionnaire for MFA thesis project

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Visual Communication Design
School of Design
College of Imaging Arts and Sciences
Rochester Institute of Technology
April, 2016

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

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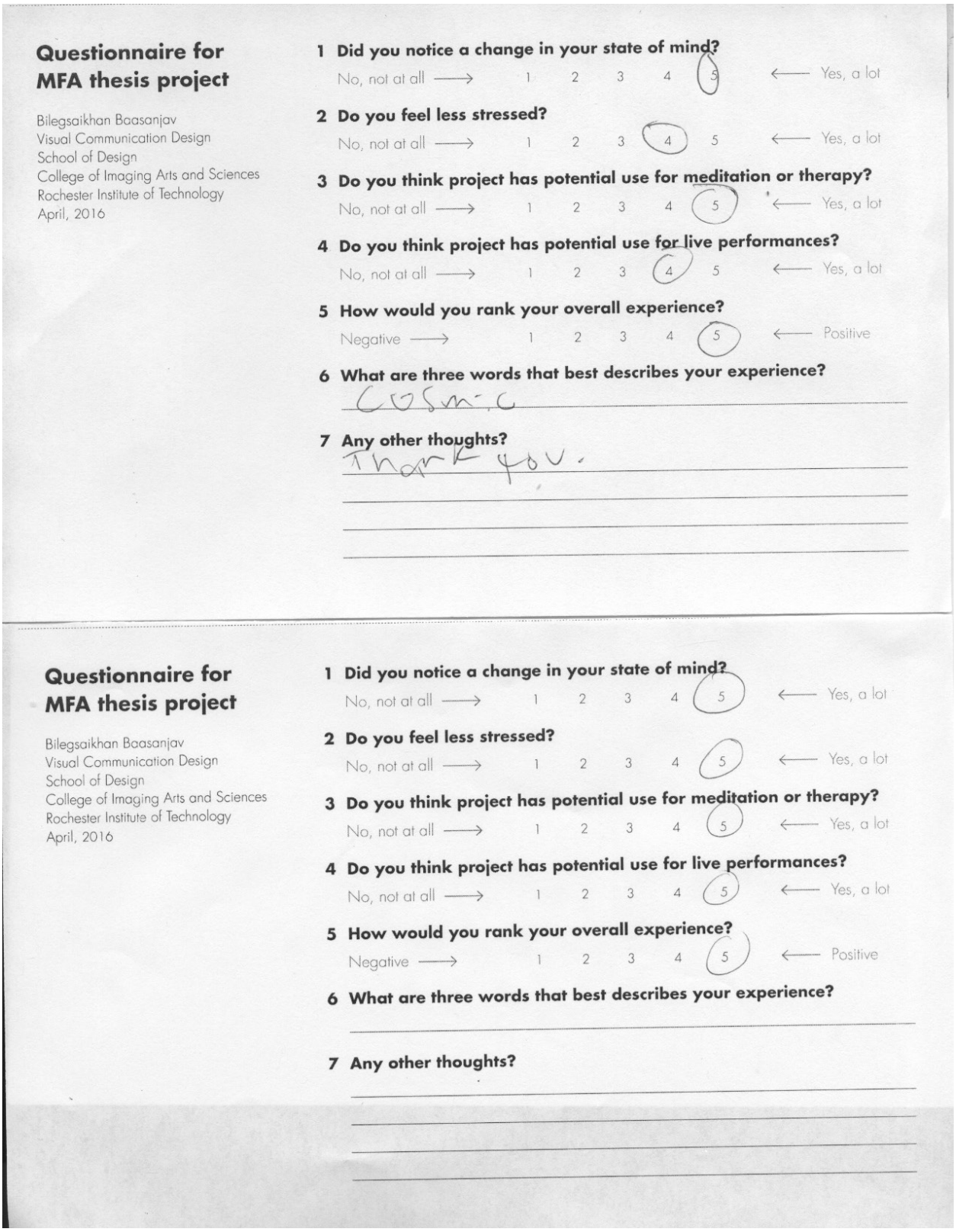
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Calming, self-reflective, meditative

7 Any other thoughts?
Without any ~~[illegible]~~ auditory/verbal instructions, this experience coaches the user to interpret, recognize, and adjust their mental state. It leaves you incredibly calm, relaxed, and clear-headed. It was very interesting to use. I would love to have this as a tool for meditative practice.



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No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Cosmic

7 Any other thoughts?
Thank you.

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6 What are three words that best describes your experience?

7 Any other thoughts?

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
really really cool

7 Any other thoughts?
awesome

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Very relaxing

7 Any other thoughts?
I really thought this was cool! a good method that could encourage/help people meditate

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?

Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?

super interesting, Awesome, exciting idea

7 Any other thoughts?

Love this!!

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No, not at all ⟶ 1 2 (3) 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?

Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?

relaxing, thought provoking, zen

7 Any other thoughts?

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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
mesmerizing, relaxing, extrasensory

7 Any other thoughts?

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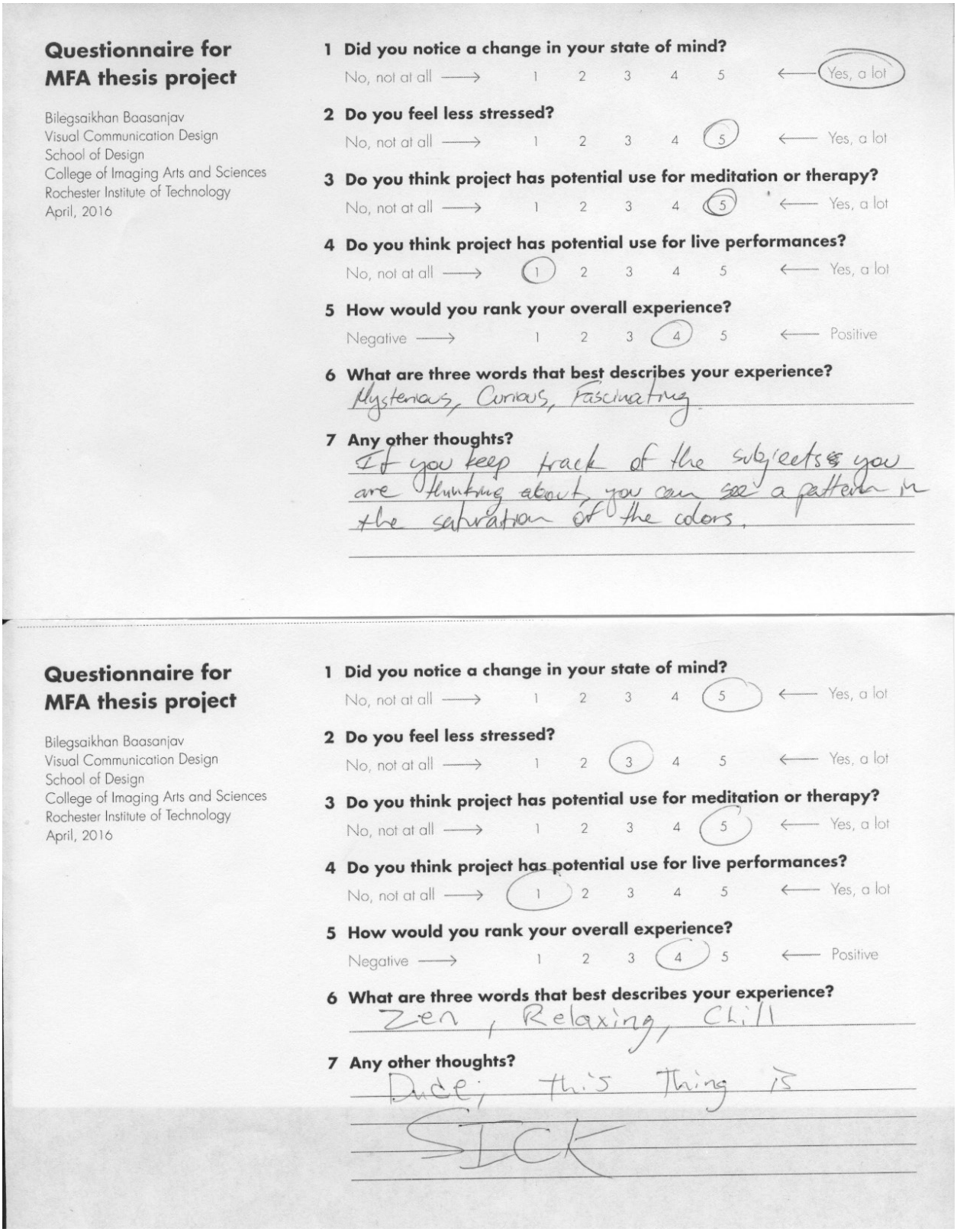
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
relaxed, chill and calm

7 Any other thoughts?



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No, not at all ⟶ 1 2 3 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 5 ⟵ Positive

6 What are three words that best describes your experience?
Mysterious, Curious, Fascinating

7 Any other thoughts?
If you keep track of the subjects & you are thinking about, you can see a pattern in the saturation of the colors.

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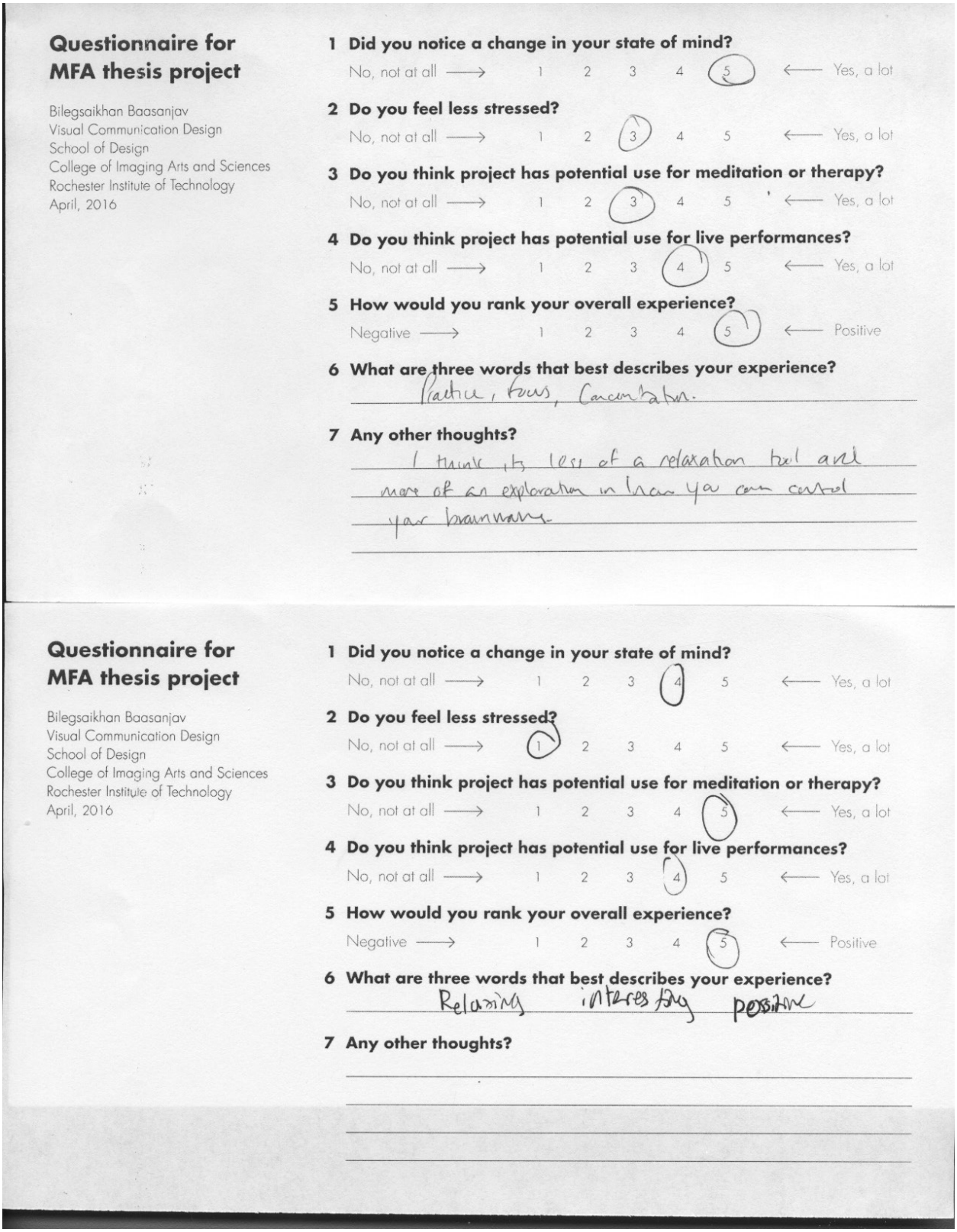
5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 5 ⟵ Positive

6 What are three words that best describes your experience?
Zen, Relaxing, Chill

7 Any other thoughts?
Dude, this thing is SICK



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No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Practice, focus, Concentration.

7 Any other thoughts?
I think, its less of a relaxation tool and more of an exploration in how ya can control yar brainwaves.

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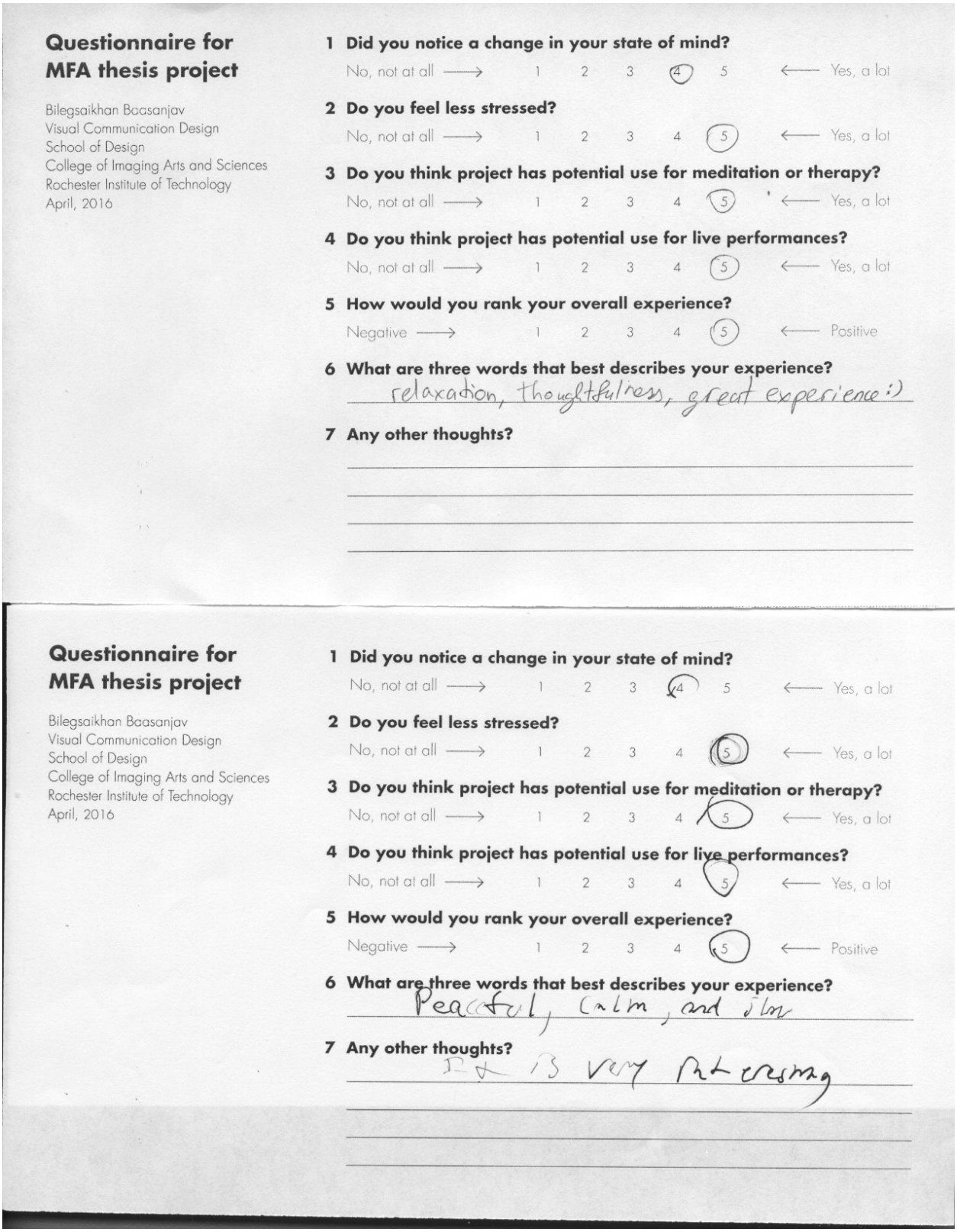
4 Do you think project has potential use for live performances?
No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Relaxing interesting positive

7 Any other thoughts?



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No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
relaxation, thoughtfulness, great experience :)

7 Any other thoughts?

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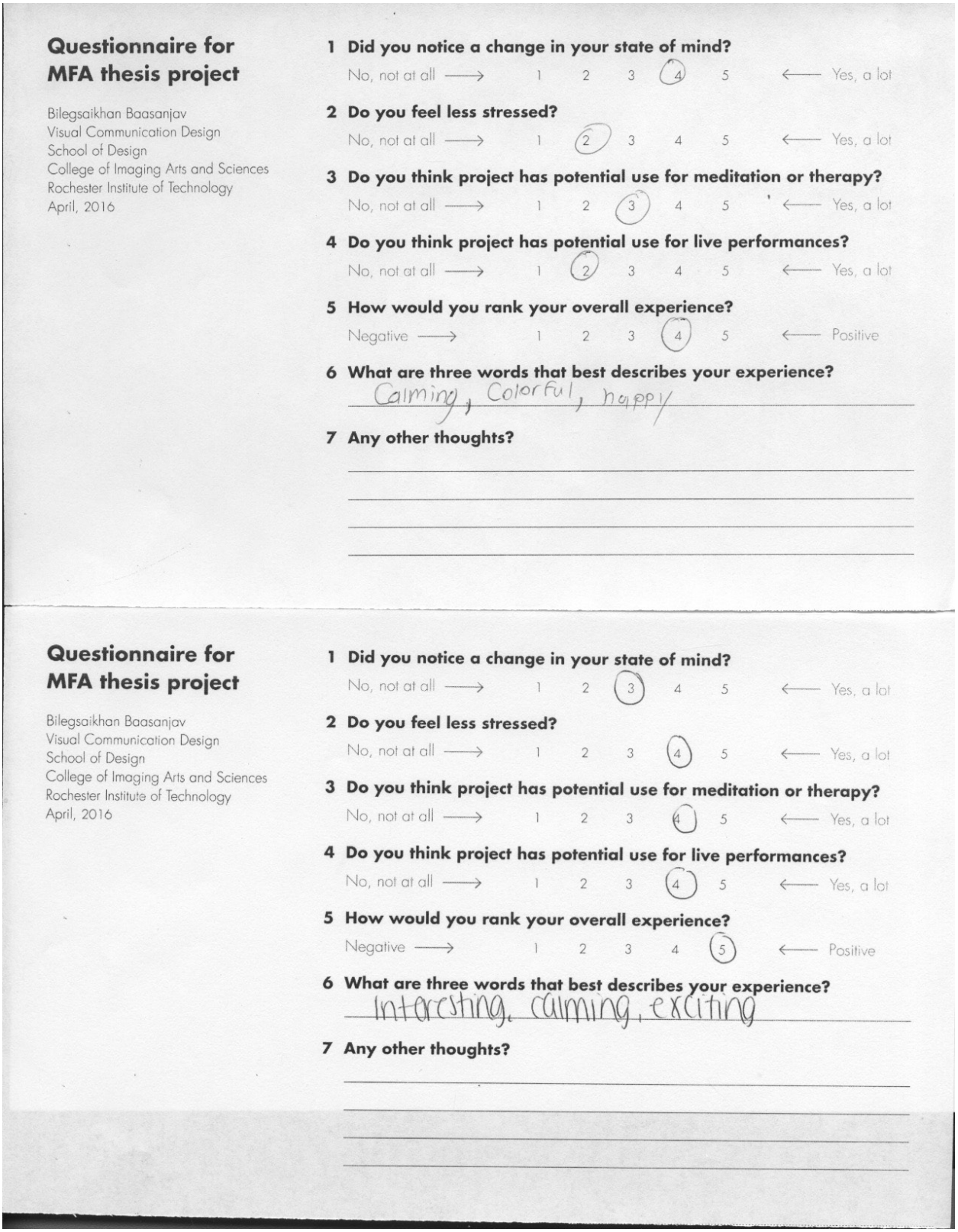
No, not at all ⟶ 1 2 3 4 (5) ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Peaceful, Calm, and Fun

7 Any other thoughts?
It is very Interesting



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No, not at all ⟶ 1 (2) 3 4 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
Calming, Colorful, happy

7 Any other thoughts?

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No, not at all ⟶ 1 2 3 (4) 5 ⟵ Yes, a lot

5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Interesting, calming, exciting

7 Any other thoughts?

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Calm, fun and a little dizzy

7 Any other thoughts?
It was awesome

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Very cool

7 Any other thoughts?

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6 What are three words that best describes your experience?
Relaxing

7 Any other thoughts?

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
fun, interesting, relaxed.

7 Any other thoughts?
I liked how it made me feel more relaxed.

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Relaxing, fun, excellent

7 Any other thoughts?
Incredibly interesting. It was so cool and relaxing.

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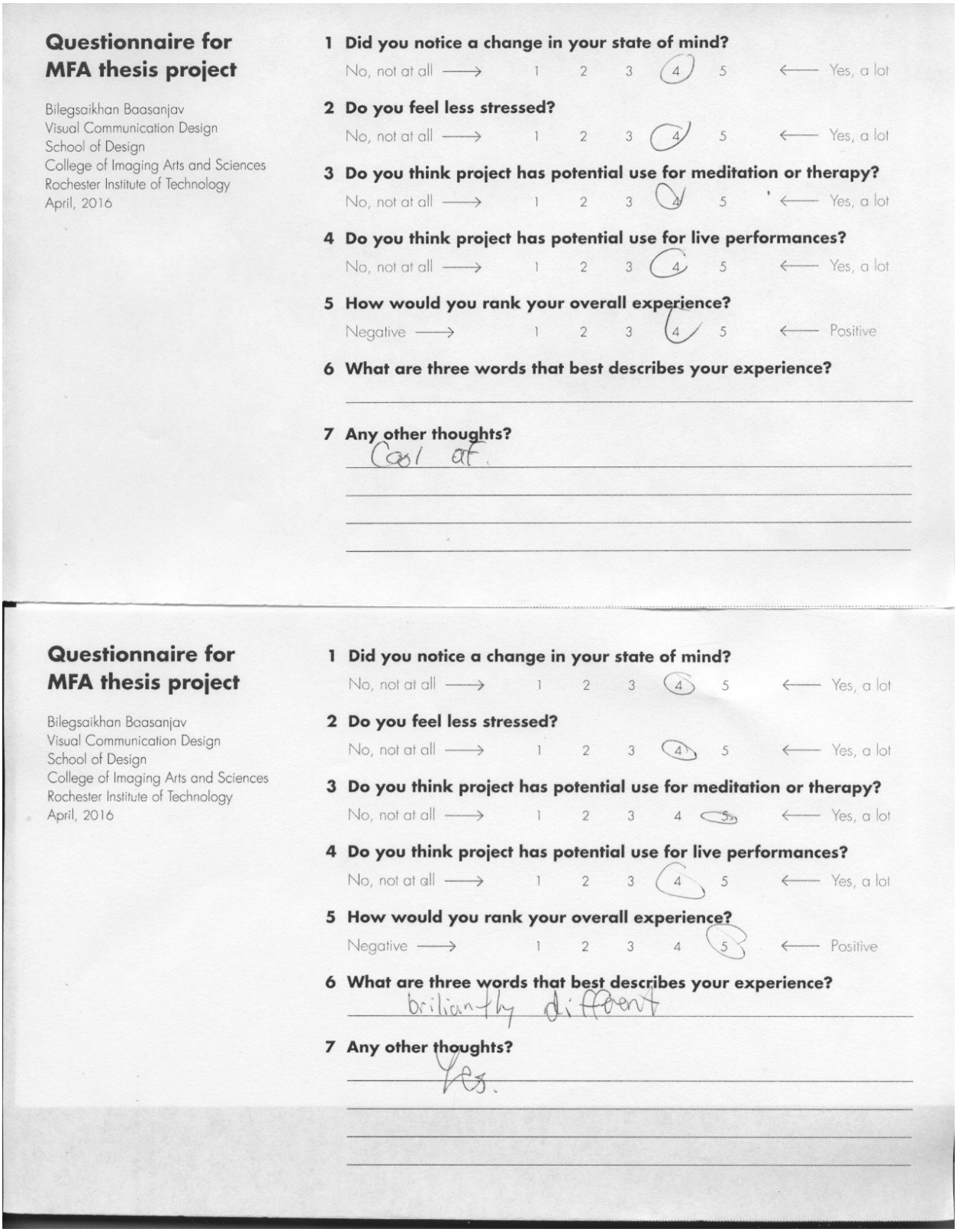

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5 How would you rank your overall experience?
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6 What are three words that best describes your experience?

7 Any other thoughts?
Cool af.

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
brilianthy different

7 Any other thoughts?
Yes.

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 4 (5) ⟵ Positive

6 What are three words that best describes your experience?
Breathing Focus Balance

7 Any other thoughts?
3D or VR would be interesting

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5 How would you rank your overall experience?
Negative ⟶ 1 2 3 (4) 5 ⟵ Positive

6 What are three words that best describes your experience?
Absorbing, curiousity, centering

7 Any other thoughts?
This is amazing. I can definitely see possible applications for meditation practice.

bibliography

psychology

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philosophy and religion

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